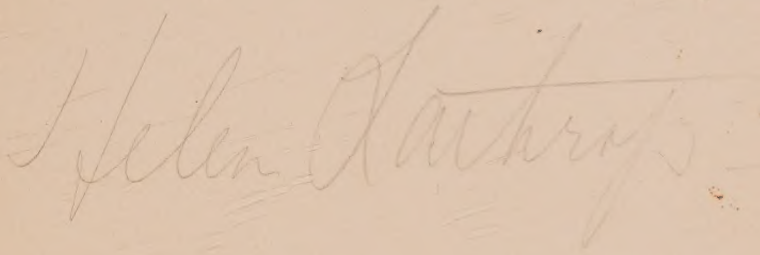

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SYLLABUS

OF

A COURSE OF LECTURES

ON

ELEMENTARY GEOLOGY

BY

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STANFORD UNIVERSITY,
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CONTENTS.

Page.

THE DATA OF GEOLOGY 6– 10

PART I.

DYNAMIC GEOLOGY, OR ROCK-MAKING AGENCIES 12–174

PART II.

STRUCTURAL GEOLOGY, OR THE MODIFICATIONS OF ROCKS 176–234

PART III.

HISTORICAL GEOLOGY, OR PALEONTOLOGY. THE ORDER OF EVENTS AND LIFE AS RECORDED IN THE ROCKS 236–270

PART IV.

TOPOGRAPHIC GEOLOGY, OR PHYSIOGRAPHY. THE SURFACE FEATURES OF THE EARTH 272–300

INTRODUCTION.

The method of presentation followed in these lectures is not intended to be a strictly logical one from a geological point of view. It is not thought that the logic of the subject as a whole is of any particular importance to the student until he shall have gained a good general knowledge of geological phenomena and of geological principles.

It is the aim to begin with those phenomena with which the average student is most likely to be familiar, and by using this familiarity to branch out so as to cover the whole field, in so far as it can be done in such an elementary course of lectures.

The order of presentation is approximately that followed in the text-books.

The student cannot be too deeply impressed with the fact that, if he is to get a real knowledge of geology, he must go out of doors and see it face to face. No amount of book study, however important and thorough it may be, can take the place of this field study. But neither must books be neglected, for they contain the results of what others have seen and thought.

The foot-note references will enable students to extend their knowledge by reading. These references are not intended to be full, but the papers cited almost invariably mention others upon the same subject, and some of them contain full bibliographies.

TEXT BOOKS ON GEOLOGY.

Manual of geology. By James D. Dana. Fourth edition. New York, 1895. 1087 pages. Price $5.00.

An introduction to geology. By W. B. Scott. New York, 1897. 573+XXVII pages. Price $1.90.

Text-book of geology. By Sir Archibald Geikie. Third edition, London and New York, 1893. 1147+XVII pages. Price $7.50.

Physical geology. By A. H. Green. London, 1882. 728+XXIV pages. Price $6.00.

Geology, chemical, physical and stratigraphical. By Joseph Prestwich. 2 vols. Oxford, 1886. 1083+LII pages. Price $15.00.

Principles of geology. By Sir Charles Lyell. Eleventh edition, 2 vols. New York, 1889. 1323+XXXIX. Price $8.00.

Traité de géologie. Par A. de Lapparent. 2me edition. Paris, 1885. 1504+XV pages. Price $10.00.

The students' hand-book of physical geology. By A. J. Jukes-Browne London, 1884. 514+XII pages. Price $2.40.

Elemente der geologie von Dr. Hermann Credner. 808+XX pages. Leipzig, 1887. Price $6 00.

Elements of geology. By Joseph Le Conte. New York, 1896. 640+XVII pages. Price $4.00.

Revised text-book of geology. By James D. Dana. Fifth edition, edited by Wm. North Rice. New York, [1898] Price $1.40.

THE DATA OF GEOLOGY.

Geology has to do with the structure and history of the earth.

Geologic reasoning is based on the supposition that the operation of geologic agencies is constant under given conditions.

Geology deals with two classes of phenomena:

I. OBJECTIVE PHENOMENA, or the materials, structure, and forms of the earth. These phenomena are:

First. Rocks and their constituents.

The earth is made of rocks.

Geologic definition of rocks.

The rocks are made of minerals.

Examples of different kinds of rocks.

Conglomerates, pebbles, pudding-stones, sands, sand-stones, clays, shales.

Igneous rocks.

Second. Structural features, or the internal conditions and changes of the rocks.

What is meant by the earth's structure.

Examples exposed in cañons, gorges, gullies, road and railway cuts, mines, tunnels and wells.

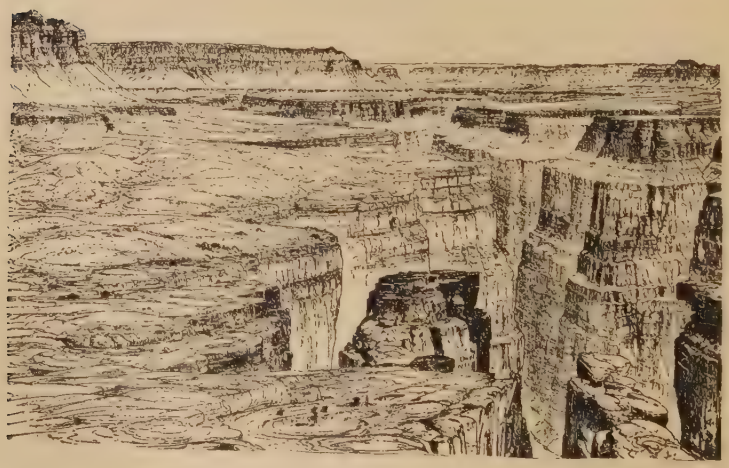


FIG. 1.—Grand Cañon of the Colorado, 2,000 to 6,000′ deep, exposing rocks lying in horizontal beds.

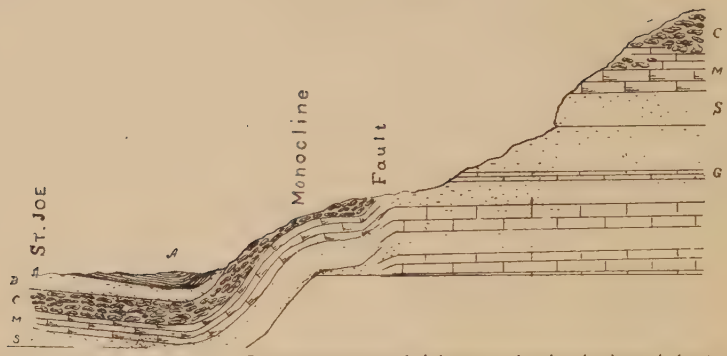


FIG. 2.—Vertical section in the Ozark mountains of Arkansas, showing horizontal, bent, and broken layers of rocks.

Third. Topographic forms, or external changes of rocks.

What is meant by topography or physiography, or the external modifications of rocks.

Examples of various types of topography and the relations of these forms to geology.

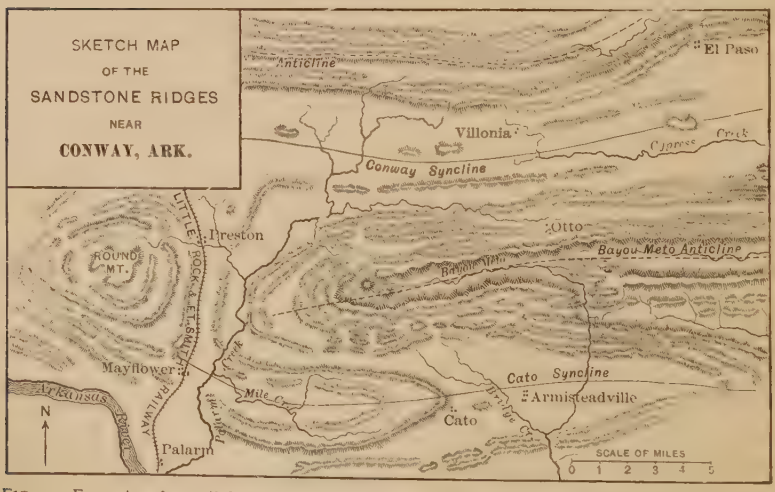


FIG. 3.—Example of parallel ridges and valleys due to folding and denudation of alternate hard and soft layers of rock.

In order to understand the forms, we must understand the structure; to understand structure, we must understand how the rocks are made and modified.

That branch of geology which deals with the topographic forms and surface features of the earth, their origin and modification, is called *Topographic Geology*, or *Physiography*. They will be treated of in Part IV.

II. Subjective Phenomena, or the processes by which those materials of which the earth is formed have reached their present conditions.

The agencies and processes of rock-making are called Dynamical Geology, and are discussed in Part I.

The earth's history as preserved in rocks is but fragmental at best. These fragments are contained in the materials, structure, and forms of the earth.

The rock records are not everywhere the same, nor everywhere equally accessible, while enormous portions of it have been obscured or entirely wiped out by the changes of time.

PART I.

DYNAMICAL GEOLOGY.

Dynamical geology is that branch which deals with rock-making agencies. Rocks may be classed as:

I. *Mechanical sediments*, or rocks deposited mechanically, either by air or by water. They are usually called sedimentary rocks.

II *Chemical deposits*, or precipitates from solution in gases or in water.

III. *Igneous rocks*, or those cooled and hardened from a fused condition.

IV. *Rocks of organic origin*, or those made by accumulations of organic matter.

All rocks have peculiarities or characteristics due to the methods of their formation. It is, therefore, necessary to understand these methods or agencies in order to know how and under what circumstances the rocks were formed.

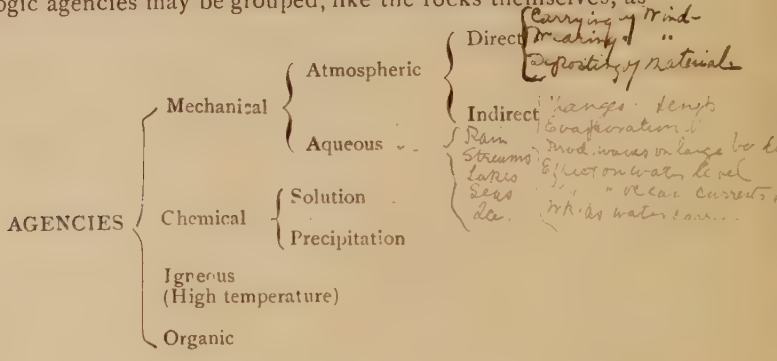
In astronomy difficult
to grasp the idea of
Space; in geology
same difficulty
Concerning time.

By radical geology
deals with agencies
which shape rocks.

Rocks have in
themselves peculiarities
in method of formation

GEOLOGIC AGENCIES.

Geologic agencies are those that either make or destroy the rocks. Geologic agencies may be grouped, like the rocks themselves, as—



THE DIRECT WORK OF THE ATMOSPHERE.

The direct geologic work of the atmosphere is done chiefly in arid regions and on sandy shores. It consists of *carrying*, *wearing*, and *depositing*.

I. THE CARRYING DONE BY THE WIND.

Distribution of volcanic dust or cinders.

For miles around Mount Shasta; Vesuvius.

In Iceland*; in South America.†

In August, 1883, eruption of Krakatoa, in Straits of Sunda; ashes fell nearly 1,000 miles southwest of there.‡

Skies made red all over the world, till November of that year, by the fine dust.§

Dust and sand storms are common in arid regions.

Burying of roads and railway tracks.

Filling of railway cuts; wind breaks.

Burial of forest on the shores of Lake Michigan.

---

*Across the Vatna Jökull, or scenes in Iceland. By W. L. Watts. 105–8, 160. London, 1876.

†Travels amongst the Great Andes of the Equator. By Edward Whymper. 125, 141, 326, 328. New York, 1892

‡ Nature, April 24, XXIX, 1884, 595.

§ Nature, December 6, 1883, XXIX, 130–3.

organic agencies = animal
or plants.

In volcanic eruption
winds carry material far
over land & sea — far
depending on size of
fragments & velocity
of wind. (Smoke of volcano
is not smoke, but sometimes steam & very fine

Burial of farms of West Portugal; Bermuda.

In Asia and Africa towns and cities have been buried.[1]

Sphinx of Egypt half buried in sand; some oases being buried.

In the arid parts of the United States, æolian deposits are sometimes 2,000 feet thick.[2]

Stamp mill buried by sand on desert 120 miles east of San Bernardino, California, 1896. Church buried.[3]

In the Argentine Republic, dust produces darkness, and obliterates landmarks and roads.[4]

Darkness caused by mineral matter in the air.[5]

Estimated that such storms carry at least 2,000 tons to the cubic mile.[6]

In April, 1863, several inches of dust fell at Peking, China; it came from the cultivated fields of Asia.[7]

In February, 1898, worn sand, probably from Sahara, fell on shipboard, 900 miles off the coast of Africa.[8]

Distribution of plants by seeds blown over the earth.[9]

Seeds with wings, etc. "Tumble weed."

Russian thistle.[10]

Diatoms.

Distribution of Animals.

Birds, blown out to sea.

Spiders, locusts, butterflies.

Origin of insular floras and faunas.[11]

Influence of plants and animals upon geology.

---

[1] Leçons de géologie pratique. Par E. de Beaumont. I, 193–4. Paris, 1845. In Palestine, see Mount Seir, Sinai and Western Palestine. By E. Hull. 145-6. London, 1889.

[2] I. C. Russell, Geological Magazine, 1889, 289, 342.

[3] See cases cited in Woodward's Geology of England and Wales, second ed., 546–7. London, 1887.

[4] Woodbine Parish's Buenos Ayres and the Provinces of the Rio de la Plata. 127–8.

[5] The earth as modified by human action. By G. P. Marsh. 525–583. New York, 1885.

[6] Dust and sand storms in the west. By J. A. Udden. Popular Science Monthly, September, 1896, 655.

[7] Across America and Asia. By R. Pumpelly. 59–60; 138–9. London, 1870. Wind as a factor in geology. By G. P. Merrill. Engineering Magazine, II, February, 1896, 596–607.

[8] Nature, March 17, 1898, LVII, 463.

[9] Darwinism. By Alfred R. Wallace. 362–374, London and New York, 1889.

[10] The Russian thistle in California. Bul. 107, Univ. of Cal. Agr. Exper. Sta. Tumbling mustard, Circular No. 7, U. S. Dept. Agriculture Div. Bot.

[11] Island life. By Alfred R. Wallace. London, 1880.

Wind raises dust-storms
common in arid regions.
This dust consists of
fine fragments of
rock-making material.
These dust-storms sometimes
bury cities & forests.

In Bermuda farms
are buried in sand. In
some parts of U. S. these
aeolian deposits are
2000 feet thick.

Many plants have
winged seeds and are blown
(dandelion - maple)

II. THE WEARING DONE BY WIND.

Wind alone does not wear rocks ; it wears with what it carries.

Effect of the impact of single particles:

Dulling of car windows in arid regions.

Wearing through of glass panes near dunes.

Wearing and rounding of telegraph poles in deserts.

Polishing of rocks in mountain passes.[1]

Faceting of pebbles [2] Examples.

Toadstool-shaped rocks, supposed to be so made; often due to softer layers.[3]

Origin of the sand blast used for grinding and ornamenting glass, stone-carving.

Wear of the sand itself.[4]

III. THE DEPOSITING OF WIND-BORNE MATERIAL.

Why wind-borne material is deposited.

If volcanic dust falls in water, or is bedded, it makes tuffs.

If rain falls through dust, it falls as mud.[5]

Wind-blown sands make dunes.

Formation and shifting of sand-dunes.[6]

Forms.

1. Lines at right angles to wind in unobstructed regions.
2. Lines parallel with winds in regions of isolated obstructions, such as bushes.

[1] 40th parallel rep. II, 159; Blake, Reconnaissance in California, 91-93; Am Jour. Sci., Sept., 1855, LXX, 178-181.

Wind action in Maine. By G. H. Stone. Am. Jour. Sci. 1886, CXXXI, 133-8.

[2] J. Walther, Denudation in der Wüste. Leipzig, 1891, plates IV and V; Max Verworn, Neues Jahrb. f. Min., 1896. I, 200-210. Davis, Proc. Bost. Soc. Nat. Hist., XXVI, 166-175, plates.

[3] Bul. U. S Geol. and Geog. Sur. Ter., IV, 1878, 831; 1873, p. 32, 36; 1874, pl. IV, 1875, p. 156. Wheeler's Survey III, 82. Natural erosion by sand in Western Territories. By G. K. Gilbert, Amer. Assoc. Adv. Sci., XXIII, 26-29. Die Denudation in der Wüste, von J. Walther, Leipzig, 1891.

[4] On the laws that govern the rounding of particles of sand. By Wm. Mackie. Trans. Edin. Geol. Soc. 1897, VII, 298-311.

[5] Woodbine Parish's Buenos Ayres. 127-8.

[6] On the formation of sand-dunes. By V. Cornish. The Geographical Journal, Mar., 1897. 278-309. (Comprehensive discussion.)

Die Denudation in der Wüste, von J. Walther, Leipzig, 1891. Das Wandern der Dünen, 513-522.

When sharp sand grains
are blown they cut in time
into rocks. In Thaxs-
the panes of a church were
cut thro'.

Also rounds surfaces.
Wind makes flat edged surfaces

Most common
materials carried by
wind are sand-dunes.
As wind blows so sand-
dunes move.

Height.

Probably only limited by accidents.

On the coast of Holland, 260′.

Western Palestine, 200′.*

Structure.

Due to methods of deposition.

FIG. 4.—Sand dune structure exposed in æolian sandstone.

Variations produced by shifting winds.

Length.

Examples: Monterey, southwest France, Holland.†

Æolian rocks.

Æolian rocks are those formed of wind-blown materials.

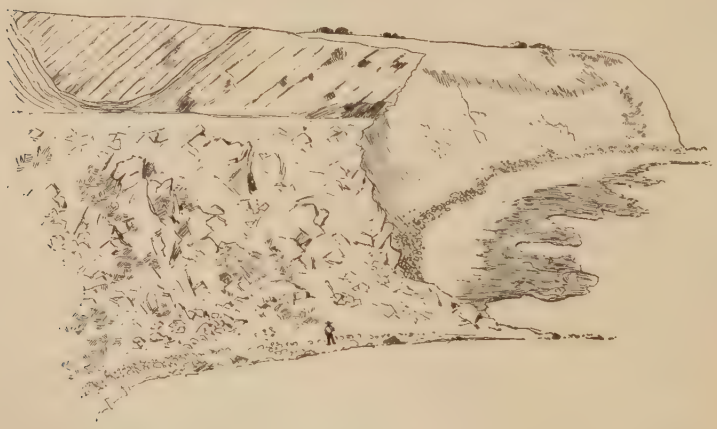


FIG. 5.—The beds at the top of the cliff are æolian sandstones. Island of Fernando de Noronha, South Atlantic.

* The Survey of Western Palestine. By E. Hull. 88. London, 1886. On the maritime dunes of the low countries. By F. C. Winkler. Report of the International Congress of Geologists for 1878, pp. 181 *et seq.*

† For physiographic value of wind, see London Geographical Journal, VIII, 1896, 264-278

Subærial deposits of the arid region of North America. By I. C. Russell. Geol. Mag., 1889, 289, 342–350.

Aeolians = anything that wind can carry —

In Bermuda these aeolians are lime deposits Shells —

These sand-dunes serious obstructions to agriculture & vegetation

Mostly of quartz sand.

In Carson Desert, Nevada, dunes of minute crustacean shells.

Near Fillmore, Utah, of gypsum.

Bermuda * and Bahamas made of æolian calcareous sandstone.

Process by which such rocks are hardened.

Supposed æolian origin of the loess of China ; 2,500′ thick.†

Cut by streams into gulches 30′–100′ deep and 4′ to 20′ wide ; houses cut in these walls.

Influence of vegetation on æolian deposits.‡

Probable origin of the "hog-wallows" of the San Joaquin Valley, California.§

Similar phenomena to be seen in most deserts.

INDIRECT WORK OF THE ATMOSPHERE.

The indirect work of the atmosphere is more important than its direct work. It may be included under the following heads :

I. Changes of temperature.
II. Evaporation.
III. Production of waves on large bodies of water.
IV. Effect on the water level.
V. Effect on ocean currents and climates.
VI. Its work as a water carrier.

*American Geologist, May, 1897, XIX, 293.

The geology of Bermuda. By Wm. North Rice. Bul. U. S. National Museum. No. 25, 7. Washington, 1884.

The Bermuda I lands. By A. Heilprin. 32. Philadelphia, 1889.

The æolian sandstones of Fernando de Noronha. By J. C. Branner. Am. Jour. Sci., April, 1890, XXXIX, 247–257.

† China. By F. F. von Richthofen. Reviewed in Am. Jour. Sci., 1877, CXIV, 487–491.

Geological researches in China, Mongolia and Japan. By R. Pumpelly. 40–41. Washington, 1866.

Loess as a land deposit. By J. A. Udden. Bul. Geol. Soc. Amer., 1897, IX, 6–9.

‡Across Vatna Jökul. By W. L. Watts. p. 76. London, 1876.

Die Denudation in der Wüste u. ihre Bedeutung. Von J. Walther. 377. Leipzig, 1891.

§ Further contributions to the geology of the Sierra Nevadas. By H. W. Turner. Seventeenth Ann. Rep. U. S. Geol. Surv., 1895-6, pt. I, 681–683. Wash. ngton, 1896.

Die Denudation in der Wüste. Von Johannes Walther. 377. Leipzig, 1891.

Hagwallows = low heaps
of dunes covering
hundreds of acres, 4 or 5
feet above ground.
It is supposed that
mats of grass cause
the hummocks by
sinking sand, & grow
blowing on.
All changes of temp-
erature cause rocks to
contract & expand

CHANGES OF TEMPERATURE.

All changes of temperature cause rocks and minerals to contract and expand. In massive or crystalline rocks the crystals expand and contract differently along their different axes. Some even contract along one axis while expanding along another.*

The rocks are composed of severals minerals interlocking; the expansion and contraction at different rates cause the minerals to slip on each other, and the mass to loosen and disintegrate.

Changes of temperature affect surface layers especially.

This produces spalling, chipping, and exfoliation in layers.

Tendency to produce rounded blocks; reason for the rounding of corners.

Rounding of basaltic columns; examples.

Called "boulders of decomposition."†

Same effect produced on hills and mountains of massive rocks noticeable in granite region. Examples: Yosemite Valley, Serra do Mar, Rio de Janeiro; interior of Africa, Georgia‡ and North Carolina.§

Granite and gneiss expand one part in about 200,000 for every additional degree at ordinary temperatures.

Annual change in temperate regions is about 150° (—25° to + 125° Fht.) for exposed surfaces.

Linear expansion for 103° over a surface of 300′=1.85 inches.

Rifts found in granite quarries caused by this expansion and contraction.‖ (See Plate I.)

* Smithsonian Miscellaneous Collections. XIV., No. 289. Tables of expansion by heat for solids and liquids. By F. W. Clark. Washington, 1876.

† Winslow's report on Iron Mountain sheet Missouri Geol. Surv., IX, 6-8, plates.

The rocks of the Sierra Nevada. By H. W. Turner. 14th Ann. Rep. U. S Geol. Surv. 480, and plate 53. Washington, 1895.

‡ Merrill's Rock-weathering, frontispiece.

§ North Carolina and its resources. Winston, 1896. Plate of Stone mountain. Op. p. 115.

‖ See example in 12th Ann. Rep. State Mining Bureau of Calif, 1894. 384. Sacramento, 1894.

Decomposition of rocks in Brazil. By J. C. Branner. Bul. Geol. Soc. Amer., 1896. VII, 255-314.

Principles of rock-weathering. By G. P. Merrill. Jour. Geol., 1896, IV, 704-724; IV, 850.

Boulders formed in situ. By G. H. Barton. Technology Quarterly. V, 401-405. Boston, 1892.

Plate XIV in Monograph XXVII, U. S. Geol. Surv.

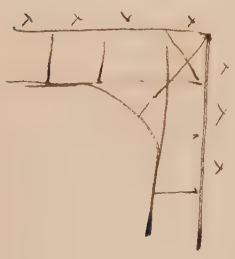
A treatise on rocks, rock-weathering, and soils. By G. P. Merrill. New York, 1897.

A granite quarry near Little Rock, Arkansas, showing sheets of exfoliation caused by expansion and contraction.

Contraction & expansion
cause rocks to disintegrate,
& will crack a broad
homogeneous surface.
When a rock is broken
it- literally means. rain,
water slips on to- it to
crevices; & so makes decay
causing acids-
Some rocks peel off in
sheets- exfoliation-

These rocks are not
always rounded by
water but in spots is
seen in Conn. Cut in 1867-
In photo. (a) is
a boulder is peeling off; ex-
foliation destroying whole
figure.
This peeling off by temp. is
one of most important features

A square work peels off in this way, thus at the corners thus gradually becoming round. Why does temp. break off in corners?



Set each space receives x change of temp. The corners rec. 2 x thus twice as much change as sides.

The ring is cracked as was caused by change of temp. but by so much original in solution.

When the temperature falls below freezing another set of phenomena is introduced by the expansion of water on freezing.

Lifting of sidewalks.
Crumbling of damp earth.
Enlargement of crevices in rocks.
Throwing down of loose fragments and blocks from cliffs.
Formation of talus slopes.
Disintegration of porous rocks.

Importance of alternate freezing and thawing.

FORMATION OF SOIL IN PLACE.

Relations of rocks and soils.
Residuary soils formed partly through changes of temperature and freezing, and partly through the chemical action of water and plants.
Why some blocks of rock are left undecayed.*
Why soil is thin on slopes and deeper in valleys.
Alluvial soils derived from residuary soils.
Method of accumulation.
Origin of the adobe soils on the University campus.
Glacial soils are derived largely from residuary soils.
Accumulation and modification.†

II. EVAPORATION.

The geological work of evaporation consists of the *formation of efflorescence* and the concentration and deposition of minerals dissolved in water. The chemical deposition of minerals will be treated under the head of "Chemical Agencies."

Formation of efflorescence.‡
Illustrated by efflorescence on brick buildings.
"Alkali" of arid regions; of Searsville creek.
All natural spring or surface waters contain mineral matter in solution. How demonstrated.

* U. S. Geol. Surv., Monograph XXVII, plate XIV, 286. Washington, 1896.
† The origin and nature of soils. By N. S. Shaler. 12th Ann. Rep. U. S. Geol. Survey, 213–545. Washington, 1892.
Geology of England and Wales. By H. B. Woodward. 548-550. 2d ed. London, 1887.
‡ Journal of the Franklin Institute, CVI, 52.
American Architect, 1884, XVI, 207–8; 267-8.
Amer. Arch., 1893, XXXIX, 30.
The Clay Worker, April, 1893, 497, 509; Dec. 1896, 443–4; Feb., 1897, 124–5; June, 1897, 517; Oct., 1897, 265.
The Clay Record, Nov. 15, 1897, XI, 17; July 8, 1898, XIII, 15.

Where soil is sandy was sandstone.
adobe comes from decomposed lava.

The royal arches in Yosemite are cracks caused by temperature. The thin sheets at bottom wear away—

The topography of high sierras caused by changes in temp — by radiation —

Cleopatra's Needle having survived thousands of yrs — in Egypt, its angles clean cut + sharp, has begun to peel off in thick layers, because of the freezing of water in cracks + on surface

When water freezes + expands it tears rocks to pieces.

In pts. of southern states which have cold down to freezing pt. we have formation of needles—

This agent has changed great hills
1st tearing to pieces by changes of temp—
2d breaking into small pieces by destruction

Water passing through rocks and soils dissolves some of the soluble minerals.

In arid regions surface evaporation causes water to come to the surface from below or within, and its evaporation leaves the mineral in small crystals over the surface. Called "alkali"; various substances, such as sulphate of magnesia, sodium chloride, etc.

Efflorescence often causes rock surfaces to disintegrate and cavities to form.

Efflorescence, being soluble, is washed off by rain.

III. PRODUCTION OF WAVES ON LARGE BODIES OF WATER.

Waves are one of the most important geologic agents.

Most waves are produced by wind moving over water.

The geologic work of waves is done at the shore line.

If water were undisturbed it would not cut land.

(The geologic work of waves is treated at length under the head of "Aqueous Agencies," pages 52–58.)

Abruptness of sea and lake shores due chiefly to the under-cutting of waves.

Skeleton islands off coasts and attacked shores.

Transportation of shingle and sand along shores.

Formation of spits.

(Spits discussed under "Aqueous Agencies," page 64.)

Damming of river mouths by wave-driven sands.

Example: Oceanside, California.

IV. EFFECT OF WIND ON WATER LEVEL.

Blowing of wind for a long time in one direction over a body of water tends to pile up the water.

Examples in long, narrow lakes, such as the "finger-lakes" of New York; on Bala Lake; Mediterranean Sea.*

In October, 1886, the west wind on Lake Erie raised the water 8′ at Buffalo and lowered it 8′ at Toledo, O.†

Tides are unusually high when the wind helps.

Effect of southeast winds on the tides in the Bay of Funday.‡

Higher tides increase the range of wave-cutting.

---

* Karamania. By F. Beaufort, 20, 21, 116. Second ed., London, 1818.

† National Geographic Magazine, Sept. 1897, VIII, 238.

‡ G. F. Matthew, Canadian Naturalist, new ser. IX, 369, foot-note.

One of most important work of
waves is transportation of material
Waves are at right angles
to wind —
On W. coast of Ireland
are skeleton islands cut
by waves —

V. EFFECT OF WINDS ON OCEAN CURRENTS.

Character and direction of ocean currents.

Ocean currents are produced partly by the lagging of water on the revolving globe.

The atmosphere as a whole lags in much the same way, but, being heated at the equator, it rises and flows towards the cold poles. This produces currents in contact with the globe, chiefly a water surface, which, as they move towards the equator, lag, and hence swing westward.

These air currents help on the ocean currents which tend to pile up the water. In the Gulf of Mexico it escapes as the "Gulf Stream" into the North Atlantic.

Probably only the surface currents are determined by winds, while the deep currents are due largely to convection.*

Climatic effect of these warm waters.

Example of northwestern Europe.

VI. THE ATMOSPHERE AS A WATER CARRIER.

The air is never still.

The great air currents are more or less definite, but they are influenced by the seasons (owing to changes of temperature), and, to some extent, by topographic forms.

Warm air takes up moisture.

When this air is cooled the moisture is condensed and dropped.

Cloud banners.

Moisture on the inside of window-panes in cold weather.

Causes of the sweating of rocks.

Warm air rises.

In the tropics, over warm seas, it absorbs the moisture and carries it upwards. This afterwards comes down as rain.

Abundant rains of the Andes due to east winds.

Why it is dry on the west slope of the Andes.

When the temperature into which the water-laden air is brought *is below freezing* the precipitation is frozen; that is, it is in the form of frost, hail, or snow.

Frost on window-panes instead of water when it is freezing cold on the pane.

Why there is snow only about the poles and on the highest mountains. Why there is usually no snow in the coldest weather.

Sleet and hail start high and freeze before reaching the earth.

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*W. M. Davis, Scottish Geographical Magazine, October, 1897.

Ocean currents are not
made entirely by wind;
caused by changes of temp
too. These are connection
currents.

The tendency of wind to lag
is greater at equator than
elsewhere.

Wind blows from equator
toward south, piles water
in S. of Mexico & forms
Gulf Stream.

Wind determines to prog.
more than aught else.

Tendency of air at equator
is to rise.

Great air currents more
or less stable but vary
with seasons.

When drop form on outside of
ice pitcher it is because air
is not warm enough to hold moist

Importance of water to life.

Water is one of the first conditions of existence : no life without it.

The most important geologic work done by the atmosphere is that which it does as a water carrier.

All the geologic work done by water is indirectly the work of the atmosphere.

In general.

The exposure of rocks to the air is fatal to the rocks.

They are almost universally broken up and destroyed.

They can last only when protected from the atmosphere.

MECHANICAL AQUEOUS AGENCIES.

The mechanical work of water is done by:

I. Rain (in its direct work).
II. Streams.
III. Lakes.
IV. Seas and oceans.
V. Ice as glaciers and icebergs.

I. THE MECHANICAL WORK OF RAIN.

Most of the mechanical work of rain is done after the water gathers in streams.

The impact of rain, however, produces certain peculiar topographic forms, illustrated by the stone-capped columns of Tyrol.*

The water of rain *runs off as streams* (p. 34), or *soaks in the ground* and emerges as springs.

Landslides.

Landslides are mechanical effects produced by rain soaking the ground.

Common in railway cuts.

Overwhelming villages in Switzerland,** Russia,† Colorado,‡ Washington.§ Bursting of peat-bogs‖ in Ireland.

*Geikie's Text-book of geology, 354–6.

**Science, Jan. 1, 1897, 21; Bul. Soc. Géol. de France, 2me ser. VII, 188. Paris, 1850.

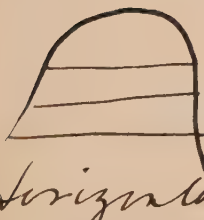
†Guide des excursions du VII Cong. Géol. Internat. XX, 30 and plate C. St. Petersburg, 1897.

‡W. Cross, Science, Dec 25, 1896, IV, 962.

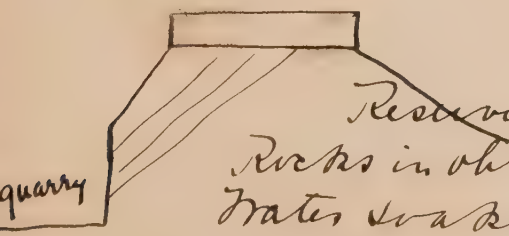
§I. C. Russell, Bul, 108, U. S. Geol. Surv, 47–48.

‖G. A. J. Cole, Nature, Jan. 14, 1897, IV, 254–6. G. Henry Kinahan, Nature, Jan. 21, 1897, LV, 268–269.

These tops protect the columns



Horizontal beds do not so easily form landslides as rocks in oblique position



Reservoir in Devity. Rocks in oblique position. Water soaked thro' & caused rocks to slide. Split & ruined reservoir.

Conditions favoring landslides:

1. Topographic form; only in mountains and hills.
2. Geologic structure.
3. Mineralogic composition.
   Ex.: clays, decayed shale, serpentine, steatite, graphite, mica, peat.
4. Water present.*

How to Prevent Landslides.

I. By draining and turning the water away from the slippery earth.
II. By planting trees where roots will hold the soil.
III. By protecting the natural supports of land liable to slip.
   Case of the reservoir at Rio de Janeiro.

II. THE MECHANICAL WORK OF STREAMS.

Origin of streams. { Relation to underground water supply. / Relation to surface waters.

The mechanical work of streams:

I. Erosion, or wearing.
II. Transportation, or carrying.
III. Deposition.

The whole process of removal is generally spoken of as *denudation*.

I. Stream Erosion.

Stream erosion is produced in two ways:

1. By impact of the water.
2. Scour or abrasion by the transported materials.

1. *Erosion by impact* against soft materials affects the bottoms and sides of stream channels.
   Illustrated by hydraulic mining.
   Lateral erosion undercuts banks of soft materials.
   Centrifugal force on the outside of the curve.

*On landslides in Switzerland, see Neues Jahrb. für Min. u. Geol. 1877, 916; 1875, 15.

Notes on the late landslip in the Dandenong Range, Victoria. By F. D. Power. Proc. Austral. Assoc. Adv. Sci. 1893. IV, 337–340.

Articles on landslides cited in British Assoc. Rep. 1885, 448, 451, 453.

Edin. New Phil. Jour. 1840, XXIX, 160.

Topographic features due to landslides. By I. C. Russell. Pop. Sci. Monthly, Aug., 1898. LIII, 480–489.

Streams come from
springs;—supplied with
water from sea face.

Lateral erosion chiefly in the lower part of a river's course.
Produces winding streams.
Swinging of streams from side to side.
"Cut-offs" of the Mississippi River.
Terras cahidas of the Amazonas.
Formation of river terraces.*

2. *Erosion by scour or abrasion* (of bottom and sides) by transported materials.†

Materials moved:

Blocks, Cobbles } Boulders.
Pebbles.
Sand.
Clay.

Effects of moving stones and sand.

Clean, clear water cannot cut hard rocks mechanically.

(*a*) *To grind rock beds and sides of streams.* (Abrasion.)

In eddies below cataracts and falls, form *pot-holes.*

Methods of grinding.
Searsville creek.
Archbald pot-hole, 40′x 20′. ‡

Lucerne, Switzerland.
Pot-holes are purely local.

General effect of the grinding of the bottom is *to cut stream channels deeper* in the rocks. The loose stones, sand, etc., are pushed along down stream, and as they go they wear and cut the bottom and sides. Bottom cutting is done chiefly in the upper and steeper parts of stream channels.

(*b*) *To bump together the materials moved.* (Corrasion.)

Process one of wearing, chipping, and rounding.
Illustrated by the manufacture of playing marbles.
Pebbles and boulders rounded in the same way.
Rounded worn pebbles are made only by the action of water as streams or waves.

*See under Physiography.

†The erosive power of rivers and glaciers. By R. M. Deely. Geological Magazine, Sept. 1897, 388.

‡ Glaciation of the Wyoming and Lackawanna valleys. By J. C. Branner. Proc. Am. Phil. Soc., 1886, 353–356.

Archbald pot-hole. By C. A. Ashburner. Second Geol. Survey of Pa., Ann. Rep. for 1885, 615–625, and plates.

Glacial pot-holes in California. By H. W. Turner. Am. Jour. Sci. Soc. Dec. 1892, XLIV, 453–489 and plate.

Open-air studies. By G. A. J. Cole, 30–32. London, 1895.

Why some pebbles are round, some flat, and some long and slender.

How water-worn stones throw light on the history of rock beds.

Rounding of sand grains can be produced only when the current is not strong enough to suspend the grains, but yet strong enough to move them. This allows them to bump over each other like pebbles. Very fine sand is angular.

Size of sand grains.

Specific gravity.

Hardness.

Distance traveled.

Agent of transportation.*

The power of a stream to wear its channel is increased or kept up by the removal by the current of the material thus produced.

II. Stream Transportation.

Muddy color of some streams, and milky color of glacial streams, due to matter carried.

Law of the transporting power of water.

Erosive power, or Power to overcome cohesion } varies as the velocity squared.

That is, velocity doubled, quadruples the force of the current.

Transporting power, or Power to overcome weight } varies as the sixth power of the velocity.

That is, double the current, and it will move 64 times as big a block.

Or increase the velocity 10 times, and it will transport a block one million times as large. †

Vast importance and enormous increase of work done by increase of velocity of streams.

Currents required to move materials in rivers:

Clay requires	0.25′	per second
Fine sand	.50′	" "
Pebbles size of pea	1.00′	" "
Pebbles 1″ in diam	2.25′	" "
Block of 5 tons	15.′	" "
Blocks of 320 tons	30.′	" "

* On the laws that govern the rounding of particles of sand. By Wm. Mackie. Trans. Edin. Geol. Soc. 1897, VII, 298–311.

† Prestwich's geology I. 83; Quar. Jour. Geol. Soc IV, 92-93.

Géologie pratique. Par Elie de Beaumont. Tome II. Du regime des rivières, 63–134 Paris, 1849.

Ann. Rep. U. S. Engineers, 1875, II. 481.

A treatise on hydraulics By M. Merriman. 251–2, N. Y., 1891.

The suspension of solids in flowing water. By E. H. Hooker, Trans. Am. Soc. Civ. Engs. 1896. XXXVI, 239–340. The last work contains a valuable bibliography of the subject.

Result of dumping all these in a stream at once.

The total result of these varying carrying capacities is *the sorting action of water*, and the deposition at separate places of coarse and fine materials. Importance of the varying currents caused by fluctuation in the volume of water or freshets.

Determination of the amount of transportation by streams.

I. *By reconstruction or restoration of the topography* or of matter removed.

In cañons of horizontal rocks. In folded regions by restoring the arches and folds. Of limited application owing to ignorance of the upper limit of the surface removed.

Only part of the record preserved.

II. *By measuring the discharge of drainage* and estimating the amount of sediments carried out

Origin of the silts of any stream.

Relations to its hydrographic basin.

Observations on the amount carried in each gallon, and the number of gallons discharged.

Method of measuring discharge.

Collecting samples at various depths, and in various parts of the stream.

Objects of the method.

Illustrated by work on the Arkansas river.

How to determine the amount of silt in discharge.

The Arkansas river in 1887–8 carried 2 grains of silt per gallon at the lowest stage and 713 grains per gallon at the highest stage.

In Nov., 1887 (lowest discharge in any month), the total discharge of silt was 16,449 tons (dry).

In May, 1888, it was 6,208,717 tons. Total for the year was 21,471,578 tons. *

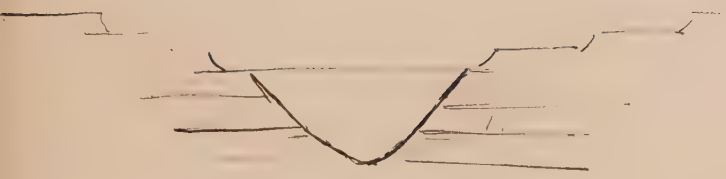
Rates of erosion and transportation by streams.

Erosion of the hydrographic basin of the Arkansas above Little Rock(=140,000 square miles) takes place at the rate of one foot in 9,433 years.

Over the Mississippi basin (1,317,500 square miles) the rate is one foot in 4,640 years.

Amazon basin 2,264,000 square miles. Drainage not always proportional to the area. Amazon hydrographic basin has twice the area of Mississippi and five times the water, owing to greater rainfall under the tropics.

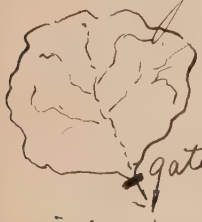
* Erosion in the hydrographic basin of the Arkansas river above Little Rock. By J. C. Branner. Ann. Rep. Geol. Survey of Ark., for 1891, II, 153–166. Little Rock, 1894.



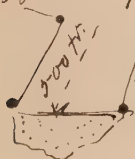
How fast is the earth carried off?

Rate of erosion cannot be determined unless source is known.

Silt = ground up rock, mud in water.



To determine amt. of silt carried out, dip glass of water, let silt settle, weigh it. Less silt at top, more at bottom, so collect water & weigh every 30 or 40 ft. or so. & average. Silt to gallon. Difficulty is water fluctuates. So repetition is necessary.



= Method of measuring amount of silt.

The rate of mechanical erosion by streams depends on:

1. The volume of water. Small stream cannot carry much.
2. The slope of the land, which determines the velocity of the streams.
3. Character of the rocks. The softer rocks are cut faster.
4. Quality and quantity of detritus or load. The hard rocks cut faster; too much chokes up or overloads the stream.
5 Climatic conditions. Differences between dry and wet climates; between tropics and cold climates; freezing loosens soil and rock.

The results of erosion and transportation.

1. Local
2. General.

1. *The local result* of erosion and transportation is to produce gullies channels, gorges, waterfalls, and valleys. The smallest ones we see made; larger ones take more time, but the process is the same. The Colorodo cañon is a most striking illustration; 2000–6000 feet deep.

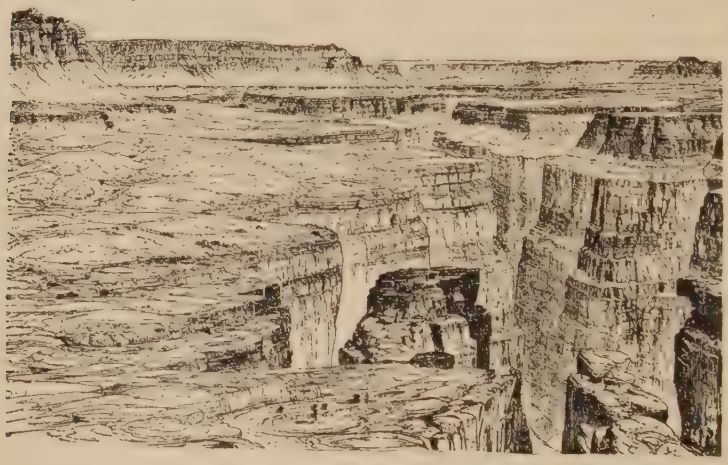


FIG. 6.—Grand Cañon of the Colorado, a gigantic gully cut by a stream in horizontal rocks.

The Colorado river rises in the Uintah and Rocky mountains in rainy areas, but it flows through an arid region. No frosts to break up, or rains to wash down the banks.

Origin of waterfalls.

Waterfalls are necessarily in stream channels.

Caused I. By a more resisting bed overlying less resisting ones. Niagara as a type.

Double the current & it will move material 64 times as large. (p. 38)

When there is little moisture to freeze, very little break-down of land.

Erosion will vary according to slope of land.

Colorado canon from 2 000 to 6000 ft. high.

Why waterfalls are in gorges.
Time required to cut back.

Caused II. By a new escarpment formed across stream channel.
These escarpments may occur :
1. On coasts.
2. In cañons, rapidly cut.
3. On the up-stream sides of faults across streams.

All valleys are more or less the results of stream erosion.
Some valleys, though modified by stream erosion, are formed as:
1. Fault valleys.
2. Synclines.
3. Between volcanic mountains.
4. Glacial valleys; these are very small.*

2. *The general result* of erosion and transportation (or of denudation) is a lowering of land surfaces.
Demonstrated in cases of large streams.
Origin of the silts carried by streams:
They come from the whole basin, though some parts are attacked more rapidly than others.

Every part of the land above water is attacked by agencies of decomposition and denudation.

The present contour of the land reveals little or nothing of its original form.

III. Deposition.

Deposition by a stream takes place in accordance with the laws of transportation.

If the stream were uniform in velocity throughout, there would be no deposition; but,

When any part of a loaded *current is checked,* deposition takes place.

In winding streams silts deposit on the insides of curves.

Why "oxbows" are silted up next to the main stream and then cut off.

Eddies silt up when the current is slack, but keep clear when the current is strong.

SOME IMPORTANT INSTANCES OF STREAM DEPOSITION.

1. *Deposition over flood-plains.*
Flood-plain, that part of a valley that is covered by water when the stream is in flood.
General silting up of bottom lands.

* Technology Quarterly, X, fig. 27, opposite p. 242.

Waterfalls slowly retreat up stream, & gradually make Canons—

Sometimes rocks are lifted up, thus form waterfall.

Waterfalls on cliffs must be new because the water always cuts back

We know almost nothing of original contour of land.

2. *Formation of natural levees.*

Levee bank raised next to stream.

How the current on an overflowed flood-plain clings to its channel.

A little of the main current constantly leaving the channel and being checked by the quiet waters: this causes silts to sink along the margin of the main stream.*

3. *Formation of deltas.*

(See under "Lakes," pages 48 and 66.)

4. *Formation of bars* at mouths of streams and estuaries.

Two sets of bars in streams flowing into the ocean.

One at the contact of stream current with quiet ocean waters.

Another at the contact of the stream with the high tide limit.

Shifting of bars, due to:

I. Varying discharge of stream.

II. Storms and waves at sea.

III. Any variation of the currents.

Deposition by overloaded streams.

An overloaded stream is one that *receives more silt than it can carry*, and hence cannot keep its channel open.

In a sense, parts of every stream are overloaded where they deposit. Such channels are kept open by freshets, or by some increase of volume and current.

Overloaded streams cut no channels, but fill them up.

Illustrations: Southern California, where streams emerge from torrents of mountains on the plains; currents strong in the mountains, but are overloaded *for the lower grade* of the plains where they deposit.

III. MECHANICAL AQUEOUS AGENCIES IN LAKES.

Fresh water lakes.

Fresh and salt lakes differ somewhat on account of difference in specific gravities of water, and on account of the floculation produced by the salt in the water.

(On floculation see "mechanical agencies in seas and oceans," page 68.)

Coarse silts sink more rapidly in fresh water, but fine silts, owing to floculation, settle more rapidly in salt water.

* The suspension of solids in flowing water. By E. H. Hooker. Trans. Amer. Soc. Civ. Engs. XXXVI. 239-340. New York, 1896.

The floods of the Miss. River. By Wm. Starling, N. Y., 1897.

Deltas.

Origin and cause.

Illustrated by the filling of mill-ponds and reservoirs from the upper end.

Illustrated by settling-pools on water supply ditches.

Lakes are all *settling reservoirs.*

Why the St. Lawrence river is clear.

Rhone waters flow into Lake Geneva muddy, but flow out clear at Geneva; delta at its upper end building constantly outward.

At Interlaken, Switzerland, a delta formed by silt-laden lateral streams has cut the lake in two.

The extension of deltas into lakes turns them into marshes and eventually into dry land.

Many of the marshes and meadows of the Sierras are silted up lakes.

Salt water lakes.

Salt lakes behave like other bodies of salt water, except that they are tideless, and consequently produce less erosion.

The amount of cutting done on shores depends on the *width of the play* of the eroding agent; hence there is less on lakes than on open seas.

Salt lakes have no outlets; they lose water by evaporation.

Changes of level recorded about Salt Lake.

IV. MECHANICAL AQUEOUS AGENCIES IN SEAS AND OCEANS.

Depth.

The ocean is deeper than the average height of mountains.

The Atlantic is 12-20,000′. Pacific's deepest 27,930′.

Mt. Whitney, Cal., 14,898′.

Orizaba, Mexico, 18,314′.

Mt. St. Elias, Alaska, 18,010′.*

Himalayas, Asia, 29,000′.

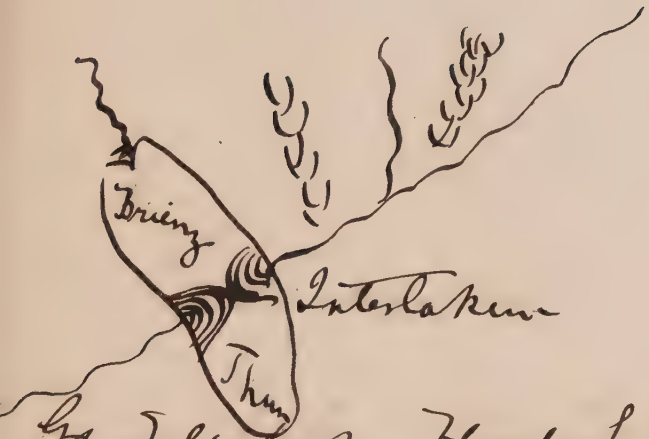
Temperature.

Challenger map, 3½° south of the equator in the Atlantic Ocean, shows the following decrease of temperature with depth:

Surface	78° Fht.	2,460′	39°
at 270′	68°	6,600′	37.4°
360′	59°	9,000′	36.5°
960′	50°	12,000′	33.7°
1,920′	41°	13,200′	33°

* Mendenhall, Nat. Geogr. Mag., V. 67.

Monograph I Geol. Survey. Gilbert



Gt. Salt Lake, Utah Lake
are only remnants of an
immense lake (Bonneville)
19570 sq. miles = area of Bonneville
2170 " " " " Salt Lake
1050 ft. depth of Bonneville

Isotherms follow contour
of bottom.

The isotherms follow the contour of the bottom.*
In many places the temperature is below 32° Fht.
Salt water freezes at 27.4°; but varies with salinity and pressure.

Currents.

The ocean's waters are everywhere in motion.
The currents flow in definite channels. Four miles an hour off the northwest coast of Cuba.

Theory of the causes of the ocean's currents.

Combination of
1. Rotation of the earth and lagging waters.
2. Trade winds, that also lag.
3. Unequal temperature of the water, producing convection.

Salinity has been appealed to, but though evaporation increases salinity, and hence density, this occurs mostly in warm regions and is compensated by temperature. Also there is a marked increase of salinity only in a few enclosed places, like the Mediterranean and Red seas.

Effect of ocean currents.
Effect on the distribution of life.†
Effects on climates.

Isotherms carried north and south on the surface.
The Gulf Stream carries half as much heat from the tropics as the arctics get from the sun.
The Gulf Stream carries more water than all the rivers of the earth.
Effect on the North Atlantic and Northwestern Europe.
Effect on rocks formed by corals and other warm water life forms.

The Tides.

Tides are the *periodical fluctuations* of the water-level in seas and oceans.
Very small on lakes.‡
At Chicago 3″ at most.

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* The voyage of the Challenger. The Atlantic. By Wyville Thomson. I, temperature charts. New York, 1878.
† Nature, Nov. 21, 1895, LIII, 64–6, and 534.
Darwinism. By A. R. Wallace. 361. London and New York, 1889.
Island life. By A. R. Wallace. 79, 262. London, 1880.
‡ National Geographic Magazine, Sept., 1897, VIII, 239.

Hot water rises to surface –

When Moon & Sun are on
Same side of Earth occur
Spring tides

Caused by moon's and sun's attraction of the fluid covering of the globe.

Spring tides occur when the two act together.

Neap tides occur when these attractions tend to counteract each other.

Height in the open ocean, 3′ to 4′.

On shores the height depends largely on shore configuration. Puget Sound, 20′; Bristol, England, 40′; Bay of Funday, 70′.*

Importance of height due to the greater range of wave action.

Power: Tides have no erosive power except in shallow water. Keep narrow channels open.†

Mechanical Work Done by Seas and Oceans.

Destructive work or erosion.

The destructive work (i. e., erosion) is done by waves and tides.

Kinds of waves:

1. Ordinary, or storm waves.
2. Extraordinary, or "tidal waves."
   - A. Bore, or pororóca, true tidal waves, produced by submarine topography.
   - B. Extraordinary waves (improperly called "tidal"), produced by earthquakes or other submarine disturbances.

1. *The destructive work of ordinary storm waves.*‡

Work confined to from 50′ below to 100′ to 200′ above tide, or as high as undermining may affect the shore.

A. *Work below tide.*

Violently destructive 50′ below tide, scattering stones and hauling out by undertow.§

Dana thinks but little breaking is done below the depth bared for the plunge, and that a depth of 20′ is rarely exceeded. "Displacement at 240′ is only a few inches."§§

Scott thinks it ceases to be effective "not far below low tide mark."‖

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* On Bay of Funday tides, Ann. Rep. Geol. Surv., Canada, new series, VII, 1894, pt. M. 14.

† Tidal erosion on the bay of Funday. By G. F. Matthew. Canadian Naturalist, new ser. IX, 1881, 368–373.

‡ Geikie's Text-book of geology, third ed. 438 and references.

§ Capt. Thos. Dickenson's Narrative of the....recovery of the....treasure sunk in H. M. S. Thetis at Cape Frio, Brazil. London, 1836. pp. 38, 42, 48, 59, 139. Tidal action as a geological cause. By T. Mellard Reade. Proc. Liverpool Geol. Soc., 15th session, 1873-4, II, 50-72.

§§ Am. Jour. Sci., 1885, CXXX, 176.

‖ An introduction to geology. By W. B. Scott. 119. New York, 1897.

Power of waves goes down
to a depth of 50 ft. +
Considerably further.

Air caught under ledges and forced out through blow-holes.

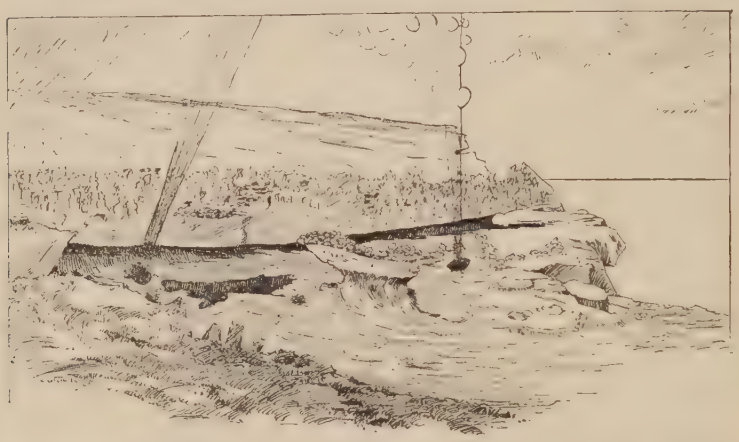


FIG. 7.—Blowholes in Ilha Rapta, Fernando de Noronha. Waves catch the air beneath the rock in the foreground and force it out vertically through two openings.

B. *Work at and above tide.*

a. *Alternate compression* and expansion of air in crevices tend to loosen rock fragments, even though not reached by the water.

b. *Impact of the water* thrown against the shore.

c. *Shingle dashed* against rocks does much cutting. Blocks weighing from two to five tons hurled against the banks; all exposed shores undercut.

d. *Shingle rolled* up and down the shore rounding stones. Milky color of water due to wear.

e. *Spray* washes mechanically, and dissolves chemically, some rocks.

Example: Fernando de Noronha.

Thrown over island at Rio de Janeiro; in the north of Scotland, lighthouse windows broken at 300 feet.

f. Hydrostatic pressure of water in crevices at heights of 50′ to 300′.

2. *The destructive work of tidal waves.*

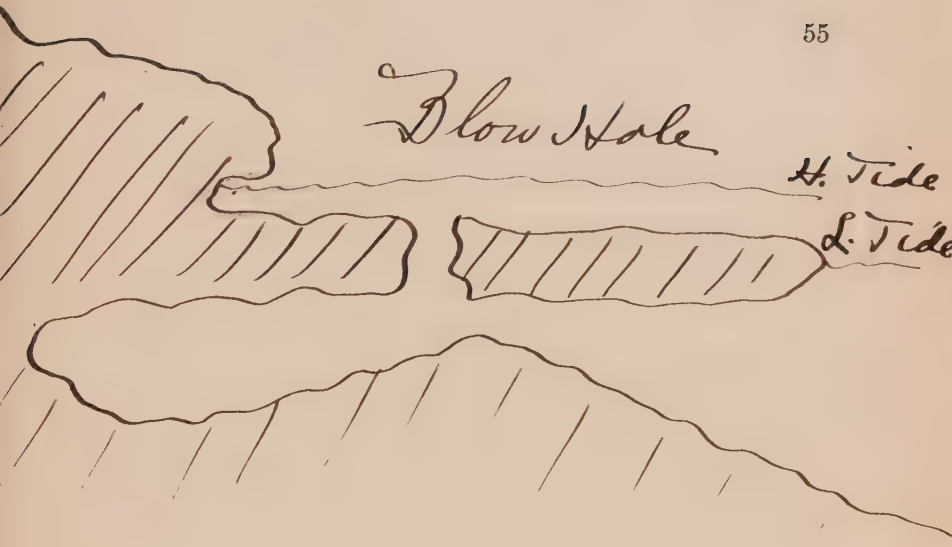
A. *Bore, or pororóca*, at the mouth of the Amazon, and of the Ganges.

Its destruction of banks, forests, islands.

Produced by topography of the bottom over which a tide wave trips up.*

*The pororóca or bore of the Amazon. By J. C. Branner. Science, November 28, 1884, IV, 488-492.

For photograph of bore, see Ann. Rep. Geol. Surv. Canada. New ser. VII. 1894, part M., p. 11, plate I.



c.) Enormous rapidity —

E.) Influence of Spray —

2A. Results of tidal waves — Silts that are carried up stream form new islands & alter up — Constant change of Topography

B. *Extraordinary waves* (sometimes called "tidal waves").

Produced by earthquakes or other submarine disturbances.

Ships left aground at St. Croix in 1867.*

Destruction by waves during the Lisbon earthquake.

On the coast of Japan, June 15, 1896, 175 miles of coast struck by a wave 10′–30′ high; some say 80′–100′. Killed 26,975 persons; wounded 5,390 others; wrecked 9,313 houses, 300 larger and 10,000 smaller boats, and destroyed $3,000,000 worth of property. Land washed off, rocks broken, shore lines changed. All in less than two minutes. Probably caused by submarine volcanic eruption 500 miles off the coast. Pumice found floating on sea; earthquake felt that day a few hours before the wave.‡

The destructiveness of waves depends upon:

1. The direction of the winds, especially during gales and storms.

   Islands half cut away, off the west coast of Ireland, where storms come mostly from the west.
2. The exposure of the coast.

   As at Santa Cruz.
3. Position of the bedding planes of rocks, or structure of the shore.
4. Character of the rocks.

   Shown by variations in the same beds at Santa Cruz.
5. Depth of the water off shore.

   Deep oceans have big waves which *break on shore;* shallows cause them to break outside before they reach the land.

   Surf as at Capitola.

Shore forms produced by wave action.

Like destructiveness of the waves, the forms produced on shores depend more or less upon:

First. The direction and force of the waves.

Second. The nature and structure of the rocks.

1. Often there is a notch cut at the line of greatest activity.

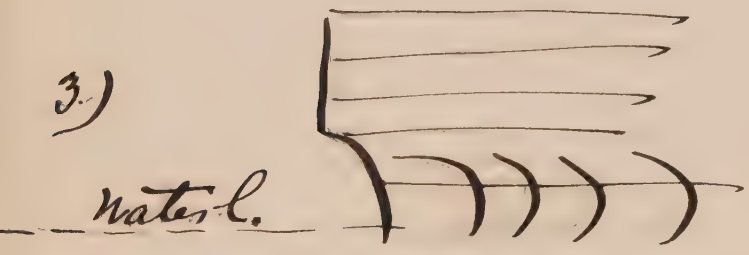
*Am. Jour. Sci., XC, 133–135. New Haven, 1868.

‡The recent earthquake wave on the coast of Japan. By Miss Eliza R. Scidmore. Nat. Geogr. Mag., VII, September, 1896, 285–289; 310–312.

Letter of Mabel Loomis Todd, The Nation, July 30, 1896, p. 84.

Stone lines

3.)



4).

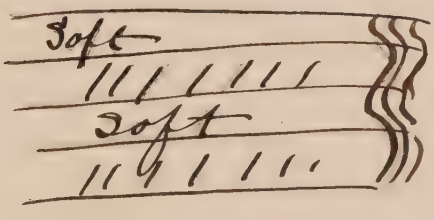


FIG. 8—Notch cut by the surf in an island of the Fernando de Noronha group. Picture made at low tide.

2. Shelves or terraces are sometimes cut at high and at low tide. This can only occur when the nature of the rock favors it.

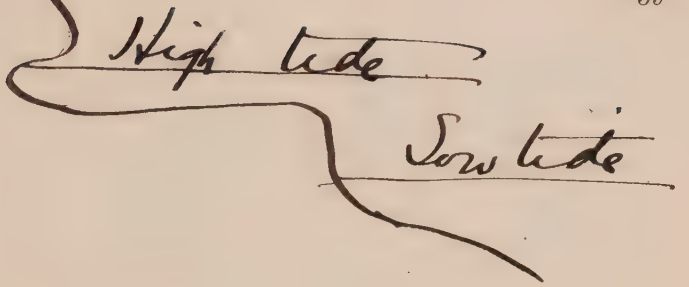
3. Caves and natural arches are cut where the variation in the resistance of the rocks and the structure favors them. Portao, Fernando de Noronha.

4. The forms are sometimes the results of protective agents on the rocks, such as seaweeds, millipores, nullipores, polyps, mollusks.*

Passing of land through beach condition.

*Across America and Asia. By R. Pumpelly. 188. London, 1870.

2)



4)

Result of molluscs + Seaweeds

FIG. 9.—The Portao, or "Big Door," an opening cut by the surf through an isthmus of eruptive rocks at the south end of Fernando de Noronha. The opening is forty feet wide.

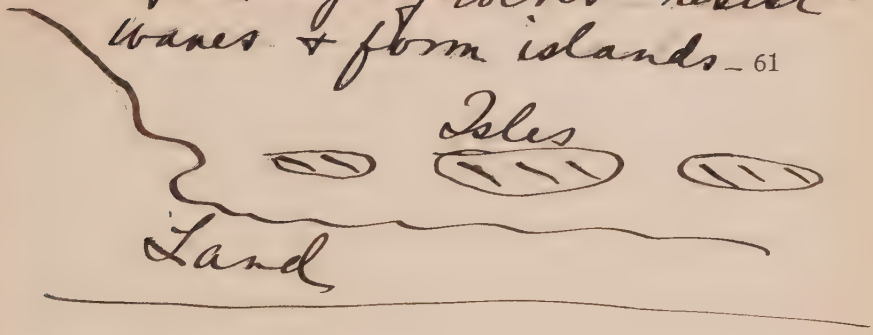
CONSTRUCTIVE MECHANICAL WORK OF SEAS AND OCEANS, OR MARINE TRANSPORTATION AND DEPOSITION.

In general, transportation and deposition take place in seas and oceans in obedience to the laws of transportation; that is, the *transporting power varies with the sixth power of the velocity*.

Transportation in the ocean is done by:

1. Tidal currents.
2. Waves.
3. Undertow.
4. Ocean currents.

Hard layer of rocks resist-
wares & form islands. 61



1. *Tidal currents* keep inlets open by the sweep, or ebb and flow, of the tides.
2. *Waves carry* beach materials where they strike the beach at an angle.
   Most important where the winds blow regularly in one direction.
   Sands and gravels carried long distances. (See "Spits," page 64.)
3. *The undertow* is the return oceanward of waters dashed on shore as waves; it is below the surface.
   It is always equal to the influx of waters on the surface as waves or surf.
   Hauls shore-made silts seaward.
4. Ocean currents are usually so far from the land that they carry but little sediment. In the case of the Amazon river, however, the sediments are swept far north by the ocean current and widely distributed over the sea floor.

Deposition in seas and oceans.

Deposition in seas and oceans takes place in obedience to the law of transportation, $P \propto V^6$.

Except that

A. The salt water being more dense than fresh, with a given velocity, carries *heavier materials*, which lose one-fortieth of their weight.

B. The salt in sea water causes floculation and consequently a more rapid settling of the *fine silts*. (Floculation, see under Deltas, p. 68.)
   Sink in one-fifteenth of the time required in fresh water.

FORMS AND ORIGINS OF MECHANICAL MARINE SEDIMENTARY DEPOSITS.

These forms are:

1. Beaches.
2. Spits.
3. Bars.
4. Sand-barrier islands.
5. Submarine banks.
6. Deltas.

1. *Beaches* are of two kinds: *ordinary beaches* and *storm beaches*.

A. *Ordinary beaches* are of sand or other loose materials derived from the land.
   Some materials are thrown up by waves; some are drawn seaward by the undertow.
   Sands and silts swept into coves and bays, accumulate and fill out the land.

Materials on Headlands
will be carried back &
put to form parts of Shore-

Dunes often originate on sandy shores.
Beds on beaches slope seaward.
Sometimes hardened by carbonate of lime.

B. *Storm beaches* are those thrown up by storm waves, and beyond the reach of ordinary waves.
They often dam rivers and form fresh water or brackish lakes at their mouths.
Examples:
Oceanside marshes, California.
Lake Merced, near San Francisco.
Lakes on the Brazilian coast.
Some with corals in the sands.

Form, or line, of the beach is determined partly:
By winds and waves.
By ocean currents.
Cuspate beaches of North Carolina and South Carolina.

2. *Spits.**
Spits are lengthwise extensions of beaches into the water.
Formed:

A. By waves sweeping shingle into quiet waters at the turn of the shore.†

B. By conflict between waves and stream currents.
These cross mouths of streams.
Vistula, Baltic Sea:
Sea of Azov.

C. By the throwing up of storm beaches on shoals.
These often connect islands.
Example: St. Paul Island, Pribilof group.
(H. L. Elliott's Pribilof Island, p. 80.)
They sometimes cause rivers to flow parallel with coast.
(Gregory's Great rift valley, p. 31.)

3. *Bars.* (Already discussed under streams, p. 46.)
Are formed by the combined action of streams and seas.
Common in most streams flowing into seas.

4. *Barrier beaches.*
Long, narrow and parallel with coast.
These merge into spits and bars.
Formed by heavy waves hurling back land silts along shallow shores.‡

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* Lake Bonneville. By G. K. Gilbert. Monograph I, U. S. Geol. Survey. Washington, 1890.

† Nature, Mar. 12, 1896, LIII, 445.
Wave-formed cuspate forelands. By R. S. Tarr. Amer. Geologist, July, 1898, XXII, 1-12.

‡ N. S. Shaler in Physiography of the U. S, 151-154.

Eventually form islands.

Examples:

Texas, Mexico, Yucatan, North Carolina, Baltic sea, Adriatic sea.

Lagoons behind the barriers silt up. Examples: Pamlico and Albemarle sounds.

Behind these barriers the land gains on the sea by silting up lagoons.

5. *Submarine banks.*

Formed wherever silts settle in the ocean for a long time.

Example: off Golden Gate are the Sacramento valley sediments.

Distinguish between a submarine bank and a wave-cut shelf.

When submarine banks come near the surface the waves pile up banks above the water, and land begins.

6. *Deltas.*

Deltas built in seas are formed in the same general way as those in lakes.

Sediments are brought from the land by streams.

Deltas at the mouths of some streams, not of others.

Probable determining causes:

A. *Character of the water* of the stream.

Clear streams can have no deltas.

Example: St. Lawrence river.

B. *Presence or absence of marine currents* on coast, whether ocean currents or tidal currents.

At the mouth of the Mississippi the tide is 15 inches, and there are no ocean currents.

At the mouth of the Amazon ocean currents sweep past it, and sediments discolor the sea 300 miles out.

Rio de la Plata, north-flowing current.

Hoang-Ho discolors the water 200 miles from its mouth; filling the Gulf of Peleche.*

Ganges and Bramapootra have deltas.

Silts probably thrown back by tides.

History of the Nile delta.

General form of deltas fan-shaped.

Building of marine deltas.

Reason of certain forms in Mississippi delta. They are the continuation of the natural levees. As the silts push seaward in deeper water, the checking of the current is at the sides and bottom, so that the bottom fills below, the sides build up at the sides, but the top silts are swept into the deeper water.

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* Across America and Asia. By R. Pumpelly. 203. London, 1870.

Influence of salt water on silts. *

Floculation.

Produced by salt, alum, acids, alkalis, cold, heat.

Alum used to floculate city water supply before filtering.

Lime does the same; why lime waters are clear.

Floculation hastens sinking of fine silts; sediments sink in one-fifteenth of the time required in fresh water, though they lose one-fortieth of their weight.

Rate of delta growth.

Varies with conditions. That of the Mississippi, one mile in sixteen years.

That of the Po, twenty miles since the time of Augustus.

Bay of San Francisco filling rapidly.

The origin of Salton Lake, California.

Delta on a rising shore.

Example at Palo Alto, California.

Position of marine sediments.

Beach deposits *slope gently seaward.*

Most deposits are *approximately horizontal* and tend to flatten their beds by filling depressions.

May cover larger areas.

Coarse ones near shore, along a narrow belt, and near their origin.

Fine ones further out and further from their source.

GENERAL CONSIDERATIONS CONCERNING MECHANICAL SEDIMENTS.

1. The sediments of streams are only the decayed and broken rocks of the land.
2. The ocean's bottom is the destiny of all the land.
3. The rate of removal depends on:
   - A. Topography.
   - B. Climate.
   - C. Structure and character of the rocks.

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* W. Skey. Chemical News. XVII, 160. London, 1868; XXXIV, 142. 1876.
W. Skey. Proc. New Zealand Inst. IV, 380–2, 1871; XI, 485–490, 1878.
D. Robertson. Trans. Geol. Soc. Glasgow, IV, 257–9.
C. Barus. Bul. 36. U. S. Geol. Survey.
W. H. Brewer. Nat. Acad. Sci. II, 165.
J. Fleming. Trans. Roy. Soc. Edin. 1815–18, VIII, 507.
E. W. Hilgard. Am. Jour. Sci. 1873, VI, 288, 333.
E. W. Hilgard. Am. Jour. Sci. 1879, CXVII, 205.
T. S. Hunt. Proc. Bost. Soc. Nat. Hist, 1874, XVI 302.
T. S. Hunt. Chemical and Geol. Essays. 10.
L. S. Griswold. Ann. Rep. Geol. Surv. Ark. for 1890, III, 192.
H. Leffman. Proc. Engs. Club Phila. 1894, XI, 293.

4. Most removal (or erosion) is done during storms or in times of freshets.

5. Erosion stops at, or not far below, the surface of the ocean.

6. Hence eroded surfaces tell of a land condition.

7. The hardening of a rock is, in a sense, an accident.

8. The law of transportation by water determines the disposition of the load of a current.

9. Thus coarse sediments can be moved only by strong currents, and fine ones can be laid down only in weak currents.

10. The nature of the sediments thus reveals the nature of the currents depositing them.

11. In an off-shore area

A. Coarse sediments will be near shore.

B. Finest sediments will be further out.

C. Coarse sediments will be in lines parallel to the coast.

D. Finer sediments will cover wider areas than coarse ones.

12. Examine rock sediments for evidence of their origin.

13. Water wearing and water bedding are done only by water, and tell of water conditions.

V. ICE AS A GEOLOGIC AGENT.

The geologic work of ice is done :

I. In the mechanical expansion on freezing, whereby rocks are chipped off and disintegrated, and earth-slopes altered (discussed on page 26).

II. By glaciers or ice streams.

III. By icebergs and floe-ice.

Glaciers.*

Outline of glaciers and their work.

Moisture precipitated where the temperature is below freezing, *falls as snow.*

Snow packs as ice, and flows as *streams of ice.*

These streams are called *glaciers.*

They obey *the law of flowing streams* in general, so far as movements are concerned, though they move very slowly.

Debris falling on the side of a glacier is carried down on top or sinks into the body of the ice.

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* The great ice age. By James Geikie. Third edition. London, 1894. (The foot-notes contain many references.)

Handbuch der Gletscherkunde. Von Dr. Albert Heim. Stutgart, 1885.

The Canadian ice age. By Sir J. W. Dawson. Montreal, 1893.

The forms of water in clouds and rivers, ice and glaciers. By John Tyndall. New York, 1872. (International Sci. Series.)

The ice age in North America. By G. F. Wright. New York, 1889.

Flowing down to warmer regions, the ice melts, and when it melts more rapidly than it is replaced by snow, the glacier ends and the debris makes a moraine or heap, while the ice, turned to water, flows away heavily charged with mud.

Origin of glaciers.

All glaciers originate above the line of perpetual snow. The line of perpetual snow at sea level is about the poles; in passing from the poles toward the equator it rises higher and higher above the earth.

Height of the perpetual snow line.

In Switzerland, 8,500–9,000′ a. t.

Kites sent up at Cambridge, Mass., Sept. 19, 1897, show that the temperature decreased 1° for 370′, when it was 63° Fht. at the surface.*

At this rate the freezing point would be at 11,470′.

At the equator the freezing point is at 16,000′ a. t.

In mountainous regions snow collects as ice in the valleys.

In high latitudes (polar regions) it collects on table lands and buries the topography.

Example: Greenland.

Compacting of snow to ice by warmth and pressure.

Illustrated by squeezing snow.

Blue ice in tunnels.

Hence the conditions necessary to the formation of glaciers are:

I. Region extending above the perpetual snow line.
II. Abundant precipitation.
III. Difference of temperature to hasten flow.

MOVEMENTS OF GLACIERS.

Rate of movement.

Swiss glaciers move 150′ to 400′ per year.

Aar glacier moves 330′ per year.

Boisson glacier moved 210′ a year for 41 years.

Muir glacier moved 7′ per day.†

Greenland glaciers move 8′ to 8 miles per year.

Rates vary according to:

1. The slope of the bed.
2. The warmth of summer.
3. The snow-fall or mass of the glacier.

* Science, Oct. 8, 1897. New series, VI, 562. Science, Oct. 22, 1897, 628.

† Studies of Muir Glacier. By H. F. Reid. National Geographic Mag. IV, 43-44. Washington, 1892.

Method of determining the rate of movement.

Transit and stakes.

General law of glacial flow is the same as that of streams.*

1. Move more rapidly at top than at bottom.
   (Owing to friction on bottom.)
2. Move more rapidly in middle than at sides.
   (Owing to friction on sides.)
3. Swing around curves with the rapid current on the outside.
4. Flow more rapidly on steep slopes.
   (Less friction.)

Explanation of ice movement (or how solid matter flows).

Theories offered to explain.†

I. In 1705 Scheuchzer suggested the freezing and expansion of water in the cracks in the ice.

II. Sliding along its bed by gravity.
   This would work like a pile of marbles or shot, since the ice conforms to its bed.

III. Pressure lowers the freezing point and makes slush of the bottom and facilitates movement.‡
   This probably helps ice movement.

IV. Plasticity or viscosity of the ice (Forbes).
   Examples of viscosity: pitch, tar, rosin, candy, asphalt. Trinidad lake.
   But these substances, though brittle, stretch; ice does not stretch.

V. *Regelation or refreezing* theory of Tyndall.
   Process shown by pressure into various forms, by cutting with wire, by the refreezing of the small broken fragments.

Glaciers are like ice fragments in a mold.

The pressure is all produced by gravity.

Hence large glaciers flow faster than smaller ones on the same slope.

Glaciers are not smooth and clean, but irregular and dirty.

Irregularities made by crevasses.

* The flow of glaciers. W. Upham. Amer. Geol., Jan. 1896. XVII, 16–29.
Deely and Fletcher, Geol. Mag., 1895, II, 153–162.
T. C. Chamberlin, editorial in Jour. Geol., III, 963–967. Chicago, 1895.
The mechanics of glaciers. By H. F. Reid. Jour. Geol., IV, 912-928. Chicago, 1896.

† Glaciers of North America. By I. C. Russell. 163–189. Boston, 1897.

‡ See Wm. Ludlow's experiments. Proc. Engs. Club of Philadelphia IV. No. 2, 93-99. Philadelphia, 1884.

CREVASSES.

Crevasses are cracks in the glacier.

Produced by tension.

I. Where ice increases its slope or flows over ridge.
These ridges may either cross, or be parallel with, the glacier.

II. Where there is a different rate of movement of one part over another.

Producing :

A. *Transverse lateral crevasses.*

Transverse lateral crevasses point diagonally up-stream.

Why they point up-stream and not down.

How they swing down-stream and are crossed by new ones.

B. *Transverse vertical crevasses.*

Transverse vertical crevasses within the ice point up-stream from the bottom, but their tops swing gradually down-stream.

Principle the same as for transverse lateral crevasses.

Longitudinal crevasses.

I. Where there is a longitudinal ridge on the glacier's bed.

II. At the ends of spreading glaciers.

MORAINES.

Rock fragments, soil, etc., falling upon the sides of glaciers, accumulate along the sides as the glaciers move forward. This material is called a *lateral moraine.*

How and why debris on one side may differ from that on the other.

Medial moraines are formed at the confluence of two glaciers by two lateral moraines running together.

Sometimes there are many medial moraines of many colors.

Baltoro glacier, in Hindu Kush, has fifteen moraines of different colors.

Number of moraines varies with the number of glaciers uniting to form the large one.

Terminal moraines are the accumulations of debris at the ends of the glaciers.

They are made of the lateral and medial moraines, and of all the solid matter carried in the body of the ice.

Forms of terminal moraines determined by the form of the end of the glacier.

Circular when the glacier is lobate.

Not water-sorted, but a heterogeneous mixture of unsorted material.

Ground moraine is the debris, soil, clay, etc., on which the ice sometimes rests.

Glacier often slides over the moraine at the end.

ERRATICS OR GLACIAL BOULDERS.

Blocks of rock carried by ice and left scattered by the melting of the ice.

Erratics often occur in large numbers.

Sometimes they are of very large size.

In Switzerland, 40–73′ long x 20′ high.

One of 240,000 cubic feet is biggest.

The Madison, N. H., boulder, 70,000 cubic feet.*

STRIÆ.

Striæ are scratches made *on the bedrock* over which ice moves, or *on the blocks held in the ice.*

Rock fragments held in the grip of the ice and pushed forward scratch the bed-rock.

The striæ cut deep at one end show the direction of the movement of glaciers.

Fragments held in the ice, ground against the bottom, are *striated* and *faceted.*

Why several faces are worn on a single block.

Differences between ice-worn, water-worn, and wind-worn pebbles.

Why all glacial pebbles are not faceted.

Some never reach the bottom of the ice.

Some have been water-worn since they were grooved.

Deep grooves of stream channels sometimes striated by ice pressed into them.

Polishing is produced when the ice is filled with sand and fine debris.

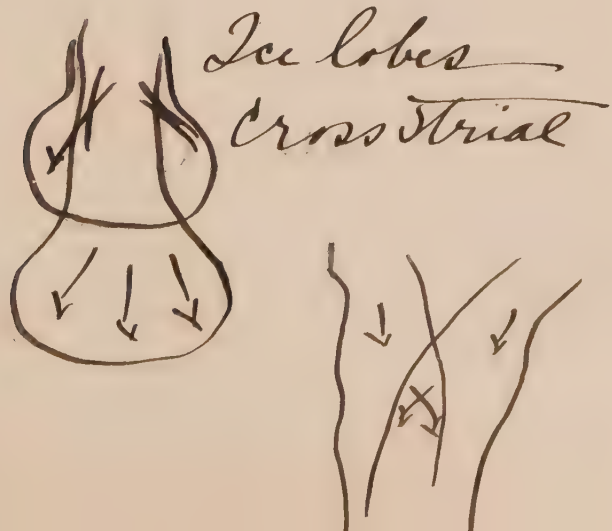
Cause of cross striæ.†

1. Spreading at the end of an ice-lobe.
2. Increase and decrease of confluent ice-streams.
3. Turning of stones.

*Crosby, Appalachia, VI, 61–70.

†Ann. Rep. Geol. Survey of Canada. New series VII, part M. 75–81. Ottawa, 1895.

Ice itself has no wearing powe
General tendencies for materials
in ice to sink.



4. Bringing of glacier under local topographic influence.

Difference between *water-wearing* and *ice-wearing* of rock in place.*

GLACIAL STREAMS.

Super-glacial streams.

Formed by the melting of the ice.

Plunge into crevasses, forming *moulins* and grinding out pot-holes.

Lucerne glacier garden.

Archbald pot-hole.†

Sub-glacial streams are the super-glacial streams after passing beneath the ice through crevasses.

Wind and cut narrow, deep channels in the bed-rock.

Channels exposed at Grindelwald and Zermatt, Switzerland.

On large glaciers they sometimes come to the surface again.‡

GEOLOGIC WORK OF GLACIERS.

Geologic work of glaciers is done as erosion, transportation, and deposition.

I. *Erosion.* Rock-set ice grinds its bed; grooves, striæ, polish.

Streams cut pot-holes wear channels.

Color and character of water; *gletscher-milch.*

Amount of wear shown approximately,

A. By topography.

B. By gletscher-milch examination.

C. By glacial debris, or drift, left over the country onre-treat.

II. *Transportation.* The materials carried are either in the form of lateral or medial moraines, materials scattered through the ice, or silts washed along by glacial streams.

III. *Deposition.* Glacial deposits are:

1. *Terminal moraines.*
2. *Lateral moraines.*
3. *Isolated boulders.*
4. *Water deposits.*

Between lobes in pools.

In ice-dammed lakes.§

* The rock-scorings of the great ice age. By T. C. Chamberlin. Seventh Ann. Rep. U. S. Geol. Surv., 1876-85. Washington, 1888.

Glacial erosion. By W. M. Davis. Proc. Bost. Soc. Nat. Hist., 1882. XXII, 19–58.

† Branner, Proc. Am. Phil. Soc., XXIII, 353–6. Philadelphia, 1886. Ann. Rep. Geol. Surv. of Pa. for 1885, 615–625. Harrisburg, 1886.

‡ See photograph, Jour. Geol. 1896. IV, 809.

§ Climbing and exploration in the Karakorum-Himalayas. By W. M. Conway, 106-179. London, 1894.

Effect of glaciation on the topography.

Effects of erosion on hills.

Roches moutonnées.

Clearing off of soil.

Effects of deposition of drift.

Moraines.

Lateral.

Terminal.

Interlobate.

Erratics.

Silts in old lakes; in ice pools.

Parallel roads of Glen Roy.*

ADVANCE AND RETREAT OF EXISTING GLACIERS.

Evidences of advance and retreat.

1. Observations of residents; glaciers in fields occasionally. Photographs at Grindelwald.
2. Striæ and drift below the present ends of glaciers.
3. Trees cut off by ice below the glaciers.
4. Difference in vegetation on old and newly glaciated surfaces.†

Swiss glaciers reached a maximum about 1820; retreated till 1840; advanced till 1850–60; retreated; some now advancing.

The unquestionable origin of glacial phenomena.

Striæ on bed-rock.

Striæ on boulders.

Old moraines; forms; mixing of material not water-sorted.

Transported blocks.

PLEISTOCENE OR ANCIENT GLACIATION.

How these phenomena led to the discovery of the former glaciation of Switzerland.

1. Striæ down the valleys.‡
2. Erratic blocks from the Alps on the sides of the Jura mountains.

Time required to carry blocks suggests length of glacial epoch: 1,000 to 2,000 years, as glaciers now move. Probably moved faster. Ice rose 4,400 feet on the Jura mountains; flowed to Lyons, France.

*W. Upham, Amer. Geologist, May, 1898. XXI, 294.

†Glacier bay and its glaciers. By H. F. Reid. 16th Ann. Rep. U. S. Geol. Surv., 421-461. Washington, 1896.

‡See map of the glaciers of Switzerland and France, in his Esquisse géologique du terrain erratique....du bassin du Rhone. Par A. Falsan. Lyon, 1883.

Reluctance with which theory of glacial epoch was accepted.

Extension by Agassiz of the theory to England, Scotland and Ireland. Shown by topography, drift, striæ.

Extension to America.

Confirmed by Agassiz landing at Halifax, N. S., in 1846.*

Glaciation in North America.

Evidences of glaciation in North America.

Striæ, or furrows.
Striated boulders.
Till, or boulder clay.
Moraines.
Erratics.

Area of glaciation.

See map.
Include parts of Rocky mountains and of Sierra Nevada mountains.
Alaska not glaciated.
Driftless area of Wisconsin.

Origin of the ice.

Did not come from the poles, but from centers of accumulation.
Labrador.
Northwest of Hudson bay.
Northwest British Columbia.
Moved southwest up the St. Lawrence valley.

Direction of ice movements, shown by:

1. Ice marks.
   Some ice marks go up hill. Why?
2. Shapes of terminal moraines.
3. Wearing of hills on ice-ward side.
4. Distribution of materials.
   Granites in Indiana and Illinois.
   Copper from Lake Superior.
5. Effect on drainage.
   Streams that flowed toward ice source were dammed up and left terraces.

Lobate forms of the ice shown by:

1. Forms of terminal moraines and interlobate moraines.
2. Direction of striæ.

Thickness of the ice.

In the eastern United States shown on mountains.

Example: Elk Mountain, northeastern Pennsylvania, glaciated 2700′ a. t., and 1500′ above the valley.†

* Geological sketches. By L. Agassiz. II, 77. Boston, 1886.
† Branner, Am. Jour Sci. 1886. Vol. 132, 362–366.

Mt. Washington 6,000′ a. t., boulders on top.
Ice thinned as the epoch waned, and finally came under the influence of local topography.
Cross striæ (see p. 78).

Evidence that the country was formerly higher to the north.

1. Hudson river gorge out at sea could only be made by subaerial erosion.*
2. Preglacial channels of Cuyahoga at Cleveland, Ohio.
Wells strike bed-rock at 228,′ 333,′ 470,′ 203,′ 392,′ below Lake Erie water level (see p. 93).
These must have been made before the glacial epoch, for they are now filled with glacial drift.
3. Possibly the drowned valleys of California, Puget Sound, and north, stood higher during the glacial epoch and sank at its end †
Elephants' teeth from St. Paul Island of the Pribilof group.
4. Terraces, or old shore lines, around Lake Ontario show that that lake since the glacial epoch has sunk on the north more than on the south.
The "ridge road" of Northern New York.

Some of the results of glaciation in North America.

The region affected varies between:

1. The narrow valleys of New England, New York and Pennsylvania.
2. The broad, flat plains east of the Rocky mountains.
3. The basin regions of the Great Lakes, now reaching (Huron) 121′ to 492′ (Ontario) below ocean level.
4. The far inland Rocky mountain ranges.
5. The Pacific ranges of the Cascades and Sierras.

It is to be expected that in so varied a region the influences would vary.

Influence of glaciation on:

I. Vegetation.
II. Faunas.
III. Drainage and topography.
IV. Agriculture.

* Geology of the sea-bottom in the approaches to New York bay. By A. Lindenkohl. Amer. Jour. Sci. 1885. CXXIX, 475–480.

† The submerged valleys of the coast of California. By George Davidson. Proc. Calif. Acad. Sci. I. No. 2, 73–103. San Francisco, 1897.
Drift phenomena of Puget Sound. By Bailey Willis. Bul. Geol. Soc. Amer. 1898. IX, 111–162.

In Subaquon, agency Sta—
Can Mathe a valley—

Rattlesnake in Mon Peak
"Ridge road" around Ontario
[illegible]
on R. Sis

I

V. Roads.
VI. Mining.
VII. Architecture.

I. Influence on vegetation. *

Cold climate crowded vegetation southward. Retreating ice left behind arctic forms.

Arctic forms left on mountain tops.

Cases of Mt. Washington, Teneriffe, Java, etc.

Swiss mountains have many forms that could only have come from the north when it was cold in the valleys.†

II. Influence on faunas.

Insects left on Mt Washington. ‡

Can now live only there; not in the valleys.

Fresh water forms migrated northward from the Mississippi drainage.§

III. Influence on topography and drainage.

Moraines; kettle holes and lakes in the moraines.

During the ice age former streams were buried and their channels filled with drift after the retreat; new channels had to be established. ¶

New drainage developed as the ice melted.

Lake Michigan drained southward; buried channels; ‖ impossibility of locating many of them.

Wabash drainage.

Terraces at Terre Haute, Indiana.

Evidences of a much larger stream.

Floods from the melting ice.

Mohawk-Hudson drainage.

Terraces. Origin of Niagara gorge. St. Lawrence rainaged last.

Lake Agassiz. **

Ponding back of the water by the ice.

Winnipeg on the old lake bed.

* Asa Gray. Proc. Amer. Assoc. Adv. Sci. 1872, XXI, 14.

† The Malay Archipelago. By Alfred R. Wallace. 91–92: London and N. Y., 1894.

‡ A. R. Grote. Proc. Amer. Assoc. Adv. Sci. 1875. XXIV. 222.

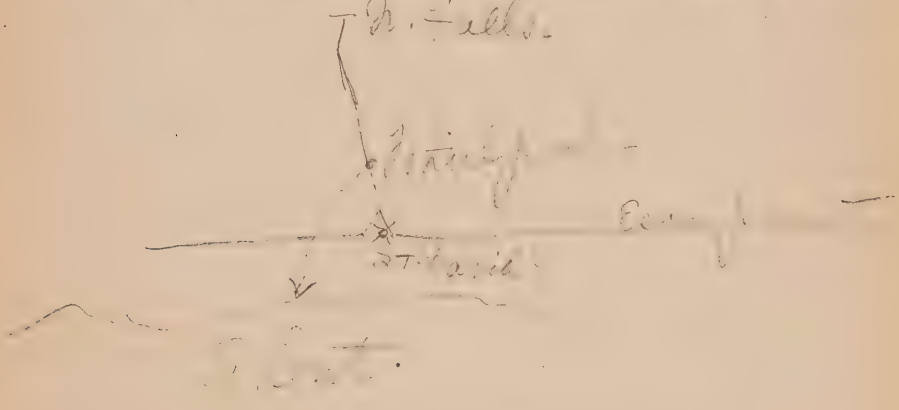
§ On the Miss. valley unionidæ found in the St. Lawrence and Atlantic drainage areas. By Chas. T. Simpson. Amer. Nat. May 1896, XXX, 379–384.

¶ The preglacial Cayahoga valley. By S. J. Pierce. Amer. Geologist, Sept. 1897, XX, 176–181; Amer. Geologist. 1896, XVIII, 223–225.

Wyoming buried valley, etc. By F. A. Hill. Ann. Rep. Geol. Surv. Pa. for 1885, 637–647. Harrisburg, 1886.

[illegible] Pleistocene features and deposits of the Chicago area. By Frank Leverett. Bul. II. Chicago Acad. Sci., 57–63, fig 7. Chicago, 1897.

** Monograph XXV. U. S. Geol. Surv. Tyrell, Jour. Geol. 1895, IV, 811-15.


St. David's

*Postglacial erosion.**

"Finger lakes" of N. Y.

The former northward drainage dammed by drift. †

Glacial lakes of the Sierras.

Donner Lake.

Fallen Leaf Lake.

IV. *Influence of glaciation on agriculture.*

Nature of glacial soils: *mixed*, *pulverized*, hence more fertile and more valuable.

Drift soils of the northwest noted for fertility. ‡

Driftless area of Wisconsin worth $10 an acre, or less.

Loess of Mississippi valley.

Origin from flooded streams. §

At Louisville, Ky.; St. Louis, Mo.; Omaha, Neb.; Kansas City, Mo.; Des Moines, Iowa; Vicksburg, Miss.; Memphis, Tenn.

Fine soil.

In Ohio the glacial border separates the less productive from the more productive parts.

V. *Influence on roads.*

Glacial gravels make good roads.

Roads as an index of civilization.

VI. *Influence on mining.*

Pot-holes at Archbald. (See p. 80)

Nanticoke disaster. ¶

Buried river channels. (See p. 87.)

VII. *Influence on architecture.*

Milwaukee cream-colored bricks from glacial clays containing lime.

St. Louis and Memphis red bricks from the loess.

Ann Arbor, Mich., etc., glacial boulders used for houses.

OTHER THEORIES ADVANCED TO EXPLAIN GLACIAL PHENOMENA.

(These are mentioned as illustrating the process by which a natural explanation is sought for natural phenomena.)

I. *Deluge* of biblical account. ‖

* Ann. Rep. Geol. Surv. Canada, New Ser., VII. 1894, pt. B., 306.

† Bul. Geol. Soc. of America. V. 348, 1893.

‡ Geol. Wisconsin II, 189. Madison, 1877.
Geology of Minnesota. I, 351–385. Minneapolis, 1884.

§ Origin of the loess of the Mississippi valley. T. C. Chamberlin, Jour. Geol. Nov.–Dec., 1897, V. 795–802; abstract, Amer. Geol. Sept. 1897, XX, 197, and Oct., 1897, 274–5.
T. O. Mabry, Jour. Geol. 1898, VI. 273–302;
12th Ann. Rep. U. S. Geol. Surv. 401–404.

¶ Buried valley.....near Nanticoke. Ann. Rep. Geol. Survey of Pa., for 1885. 626–636. Harrisburg, 1886.

For geological explanation of the deluge see La face de la terre. Par E. Suess. 25–95. Paris, 1897.

But the materials are not water-sorted.
The marks are not water-marks.

II. *Tipping up of* the north end of America.
But soil and rock are left on steep mountains; could not have remained if the surface had been tipped up.

III. *Waves of folding rocks.**
Such waves would have thrown material in the air and sent it bumping over the surface; the grooves showed that it stayed on the earth over long distances.
Besides, there are rock folds outside of the glaciated areas.

IV. *Iceberg theory.*†
But cornice-shaped, overhanging ledges are grooved beneath; striæ go straight over hills and valleys; bergs would have turned aside.

V. *Tail of a comet.*
Phenomena should have covered the whole earth; they do not.

OBJECTIONS FORMERLY URGED TO THE GLACIAL THEORY.

I. *The striæ show that the ice moved up hill.*
Some up-hill movements are local.
In the St. Lawrence valley, the slope has changed since the glacial epoch.

II. *Present climate* would be colder.
But 5°-6° lower temperature would bring the Swiss glaciers to Geneva; hence a very slight change of the annual temperature would cause a glacial epoch.

III. *Agassiz's theory of South American glaciation.*
This theory was that a glacier formerly flowed down the Amazon valley.‡
This proved too much; life would have been extinct.
This theory not found correct.§

DATE OF THE GLACIAL EPOCH.

Can be shown by the geologic work done since glaciation.
Case of Niagara Falls: estimates range from 3,500 years to hundreds of thousands of years.¶
Case of St. Anthony's Falls, Minneapolis, about 8,000 years.‖

*H. D. Rogers, Amer. Jour. Sci., 1844. XLVII, 274, *et seq.*

† Acadian geology, by J. W. Dawson, 64, 73, 2d. ed. 1868.

‡ Atlantic Monthly, July and August, 1866. Geological Sketches. By L. Agassiz. II. 153. Boston, 1886.

§ The supposed glaciation of Brazil. By J. C. Branner. Jour. Geol., I, 753-772. Chicago. 1893.

¶ Niagara falls and their history. By G. K. Gilbert. Physiography of the United States, 235-6.

‖ N. H. Winchell. The Geology of Minnesota. Vol. II of the final report. 313-341. St. Paul, 1888.

LENGTH OF GLACIAL EPOCH.*

Was man here during or before the glacial epoch?

Implements should be in the drift if he was here.

Trenton gravels.†

Minnesota.

Stump and root holes.

Burrowing of animals.

In Europe.‡

WILL THE GLACIAL EPOCH RECUR?

Depends on cause or causes.

If the cause recurs, the epoch will.

If the cause is astronomic, its return is to be expected.

Evidences of interglacial epoch.

Several lignite beds in the glacial deposits near Zurich, Switzerland.

Topographic variation and difference in oxidation in Illinois, Indiana, and Yosemite Valley region.

Shells in wrinkled loess.

Nature of marine fossils interbedded with drift.§

Evidence of previous glacial epochs.¶

In the Carboniferous rocks of India and South Africa.

In Tertiary or pre-Tertiary rocks in South Australia.

Hence the glacial epoch may return.

The conditions move slowly.

CAUSES OF A GLACIAL EPOCH.

Evidently the climate must have been different, though not necessarily arctic.

Leblanc thinks an average of 7° Cent. lower than now would produce glacial epoch.‖

* See F. B. Taylor, Jour. Geol., 1897, V. 421–465. Makes retreat from Cincinnati, Ohio, to Makinac 75,000 to 150,000 years, and glacial epoch 150,000 to 300,000 years or more. W. Upham, Am. Geol., October, 1897, XX, 268. Geikie's Great Ice Age, 812–815.

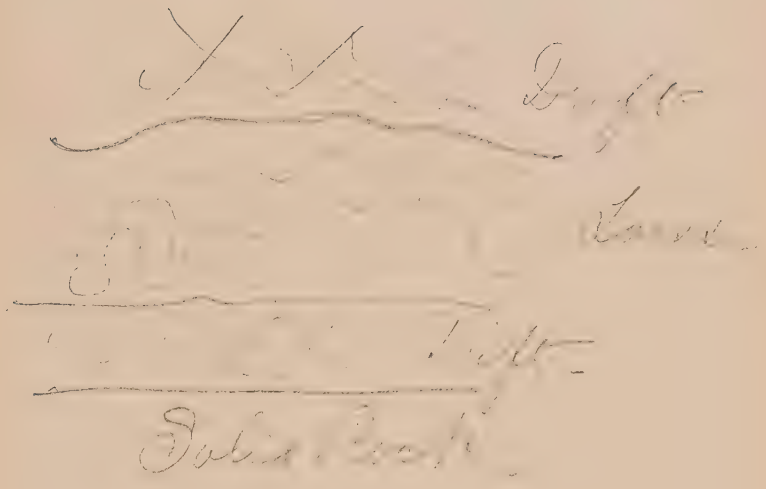
† G. F. Wright and A. Hollick, Science, October 29 and November 5, 1897. W. H. Holmes, Jour. Geol., 1893, I, 15–37 and 147. Science, new ser., Vol. VI. 1897. Several papers in Proc. Amer. Assoc. Advancement of Science, 1897. XLVI, 344–390.

‡ Man in relation to the glacial period. By Dr. H. Hicks. Nature, February 24, 1898, LVII, 402.

§ On the interglacial submergence of Great Britain. By H. Munthe. Bull. Geol. Institution of the Univ. of Upsala. 1898. III, 369–411.

¶ Neues Jahrb. f. Min. 1896, II. 61–86, and plate V, Bibliography. Geol. Mag., 1886. III, 492–495. For bibliography, see Amer. Geol. Mag., 1889. III, 299–330. The great ice age. By James Geikie. Third ed. 817–826. London, 1894.

‖ Bul. Soc. Géol. de France. 1re series, XIV, 600–611. Paris, 1843.



Temperature falls 1°C. for 188 metres in elevation.

Snow line in the Alps is at 1,200ms; a decrease of 5° in the temperature of that region would bring the ice down to 260 metres, or below Geneva.

Difference of temperature may have been due to geographic or astronomic causes.

Suggested geographic causes.

1. Change of ocean's currents.
2. Change of trade winds.
3. Elevation of land above snow line.
4. Change in distribution of land and water.

We have no evidence of such changes during the glacial epoch.

*Supposed astronomic causes.**

5. Increase of the obliquity of the ecliptic.
6. Combined effect of precession of equinoxes and of the eccentricity of the earth's orbit.
7. Changes in position of earth's axis.

In Tertiary times it was warmer near the north pole, as fossil plants show.

8. The turning of an exterior crust over a fixed core.†
9. Variation of the heat radiated by the sun.
10. Variation of the temperature of space.

The planetary system may pass through cold and hot belts.

11. Decrease of the original heat of the earth.

We have to account for many glacial epochs.

Certainly due to *lowering of the snow line*, whatever may have caused that.

ICEBERGS.

Formed by sea water lifting the ends of glaciers.

Humboldt glacier, Greenland, 60 miles across at the end.

Muir glacier, Alaska, two miles across at the end.

Bottoms set with stones and debris.

Floating, they carry away this debris for thousands of miles.

Icebergs melt and the stones they carry fall to the bottom.

Banks of Newfoundland.

Stranding of bergs in shallow water.‡

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* Discussions on climate and cosmology. By James Croll. Edinburgh, 1885. Climate and time in their geological relations. By James Croll. Edinburgh, 1875.

Island life. The causes of glacial epochs. By A. R. Wallace. 121–162. London, 1880.

† Sir John Evans, Proc. Roy. Soc. 1866.

‡ Striation by dragging bergs. Chalmers' Geol. Sur. of Canada, VII. Par M, 104–106. Ottawa, 1895.

Proc. Liverpool Geol. Soc. 1895, 383, 386.

Only one-eighth to one-seventh part out of water.
Can ground in 2,000′ of water.
Contorting of drift by dragging.
Large area south of the glaciers probably affected.

CHEMICAL AGENCIES.

The operations of chemical agents are, for the most part, invisible; but the results of such operations become apparent with time.

When rain falls on the earth the water does either *mechanical* or *chemical* work.

I. It flows off over the surface as freshets (doing *mechanical* work), and returns to the air by evaporation.

II. It soaks into the ground, to emerge as springs or to be evaporated from the soil surface (doing *chemical* work).

III. It reaches the sea by underground channels (doing *chemical* work).

All streams, spring, and well waters contain mineral matter in solution.

This is shown by evaporation of the water.
Mineral matter is derived from the rocks passed through.
Many of these minerals are considered insoluble in water.

Why the minerals are in solution.

The water is not simple, pure water.

The solvent power of water is increased by:

I. *Carbonic acid* (CO_2) derived from the air.

II. *Nitric acid* derived from the air.
Produced by electric discharges.
More abundant in the tropics.

III. *Organic acids* in the soil.
Carbonic acid from the decay of plants; from the breath of burrowing animals.
Humic acids from the decay of organic matter.*

IV. Increase of pressure on the water column, which increases its dissolving power.

V. Increase of temperature, which increases dissolving power.

Amount of dissolved matter in streams.

The amount dissolved varies greatly.
No two streams are alike.
The same stream varies from time to time.
How the amount is determined.
Measure of discharge frequently.
Determination of matter in samples.
Examination of the Arkansas river water.

* Phillips' Ore deposits, 2d ed., 37. London, 1896.

Chemical organic work for the
Year & part the [illegible]
Water from Abycentum, the
Mineral Matter Left as usual
on Evaporation. Found absorbed
Mineral Matter

In solution varies from 11 to 71 grains per U. S. gallon.
Removed in solution in one day from 13,000 to 68,000 tons; in the year 1887-88 the total removed in solution was 6,828,350 tons.
*All of this is invisible.**
Minerals in solution mostly salt, gypsum, epsom salt, lime carbonate.

Difference between streams.
Due to rock differences of hydraulic basins.
Due to the nature of water (i. e., the contained acids).

Difference in the same stream due to:
Drainage coming at different times from different parts of the basin, where the rocks differ.
Drainage sometimes from underground, sometimes from surface water.
Concentration of water by evaporation.

Effects of Chemical Erosion.

Rocks are minerals; some minerals soluble, some nearly insoluble, but all soluble with time.
Materials removed are minerals dissolved from the rocks; that is, part of rocks.
Chemical action results in the *decomposition* and *removal* of rocks.
Decomposition and alteration of rocks,† result in:

1. Soils (residuary).
   Depth of rock decay.
2. Clays largely kaolin.
3. Kaolins from feldspar.
   Nature and form of kaolin beds.
   Only in region of feldspathic rocks, or redeposited.
4. Concentration by removal.

Solution and removal of rocks result in:

1. Etching.‡ Examples.
2. Caves.

The Formation of Caves.

Natural caverns are formed in four ways:

1. By the removal of rock in solution.
2. By the underflow of lava beneath hard crust.
3. By the mechanical action of waves on coasts.
4. By the differential weathering of cliffs.

* Monograph XI of U. S. Geol. Survey for water of 20 rivers. (Table A.) 176.

† Weathering of diabase near Chatham, Virginia. By T. L. Watson. Am. Geol., Aug., 1898, XXII. 85–101
Am. Jour. Sci. 3 ser., XXVI., 195; Amer. Naturalist IX. 1875, 471; Annales des Mines 7 me ser., VIII, 698. Paris, 1875.

‡ Mount Seir, Sinai, etc. By E. Hull. 20.

1. *Differential solution and removal* of rock, aided by mechanical wear.

Mammoth Cave, Kentucky, has 35 to 40 miles of tunnels along which one can walk, besides many miles of smaller ones along which one can creep.

Cavern 70′ to 200′ high.

500 caves in Edmonson county, Ky.*

The limestone regions of Kentucky extend into Indiana, Tennessee, Arkansas, and Missouri. Wyandotte cave, Ind.;† Nicajack cave, Tenn., Luray cave, Va.‡

Why the great caves are in limestone regions.

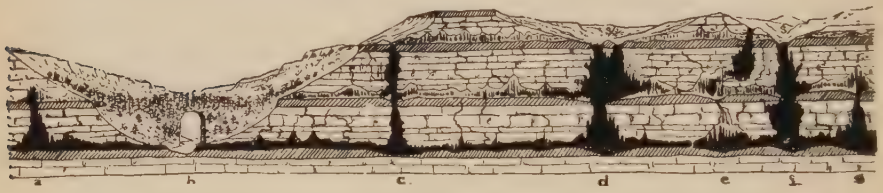


FIG. 10. Ideal section through a region of horizontal limestone beds showing caves, sink-holes and natural arches (Shaler).

The processes of solution and removal.

Such caves formerly supposed to be formed only above ocean level; why.

But waters from the land do discharge beneath the ocean, hence there must be rock removed below sea level §

2. *By the underflow of lava* beneath a cooled hard crust.

Method of formation.

Such caves only in volcanic regions.

The lost streams of volcanic regions in some cases flow through these caverns.

Kildá river, Iceland, two miles long; the rest of it is below ground.¶

3 *By the mechanical action of waves* on coast lines. Processes of the wave work.

* The Mammoth cave of Kentucky. By H. C. Hovey and R. E. Call. Abstracts of papers by H. C. Hovey, Amer. Geol. Oct. 1896, XVIII, 228.

†Indiana caves and their fauna. By W. S. Blatchley. 21st Ann. Rep. Dept. of Geol. (of Indiana) 121–175. Indianapolis, 1897.

‡Amer. Geologist, Oct. 1896, XVIII, 228.

§ For instance of fresh water discharging beneath the ocean see Shaler in Bul. Geol. Soc. Amer. 1895, VI., 155

¶ Iceland; its volcanoes, geysers, and glaciers. By Charles S. Forbes, 112, 145–148. London, 1860.

Kilauea, the home of Pele. By Wm. Libbey. Harper's Mag., Oct. 1897, 719.

For illustration of Hawaii caves see Scott's Introduction to Geology, 44–45.

Caverns made in this way seldom go far into the rocks.
Examples at Santa Cruz, California; at Santa Catalina Island; at Fernando de Noronha. (See plate II. and Fig. 8, p. 58.)

4. *By differential weathering* in cliffs.
Processes of weathering.
Why caves are formed in one bed and not in another.
Uses made of cliff caverns.*
(See plates III. and IV.)

BLOWING, "BREATHING," AND SUCKING, CAVES.

Movements of air due to varying temperatures inside and outside of the caverns.
In summer the inside air is cooler and descends.
In winter it is warmer and rises.
Flows out of Mammoth Cave at 54° in summer.†

SINK HOLES.

Sink-holes are formed by the solution and downward removal of rocks at the surface, or by the falling in of roofs of caves.
Found chiefly in limestone regions.
Due to solubility of limestone.
Examples found chiefly in cave regions of Kentucky, Tennessee, Virginia, Missouri.
Eden Valley, Ky., covers 2,000 acres;‡ 1,000 sink-hole in that county.
Ponds made by puddling clays in sink-holes.
Underground drainage of cave regions.
Mammoth springs.
Why they fluctuate so little in volume.
Method of tracing streams by the use of fluorescein.

NATURAL ARCHES.

I. By the destruction of caverns.
Natural bridge of Virginia in synclinal fold.
In limestone or volcanic regions.§ (See Fig. 10, p. 102.)

*The cliff ruins of Canyon de Chilly, Arizona. By C. Mendeleff, Sixteenth Ann. Rep. Bureau of Amer. Ethnology. 79–198 with plates. Washington, 1897.

A summer among cliff-dwellers. By T. M. Prudden, Harper's Mag. Sept. 1896, XCIII, 545–561.

† The Mammoth Cave of Kentucky. By Hovey and Call, 9.

‡ The Mammoth Cave of Kentucky. By Hovey and Call, 4.

§ Natural arches of Kentucky. By A. M. Miller, Science, June 24, 1898, VII, 845–6, illustration.

The natural bridge of Va. By C. D. Walcott. Nat. Geogr. Mag. V., 59–62. Washington, 1893.

Voyage de Humboldt et Bonpland, première partie. Atlas pittoresque, pp. 9–13. Paris, 1810.

PLATE II.

Cueva Valdez, a surf-cut cave and natural arch on Santa Cruz island, 30 miles off the coast of Santa Barbara, California.

—From Land of Sunshine Magazine.

PLATE III.

Natural caverns used as houses by the "Cliff-dwellers," Walnut Cañon, near Flagstaff, Arizona.

—From Land of Sunshine Magazine.

Ruins of the Cliff-Dwellers, Walnut Cañon, near Flagstaff, Arizona.
—From Land of Sunshine Magazine.

II. By encroachment of sea on isthmus or peninsula.
Examples: Santa Cruz, Calif. Fernando de Noronha.
(See Fig. 9, p. 60, and plate II.)

Chemical Deposition.

It has been shown that *solution* is due to
1. Acids in the water (derived from various sources.)
2. Pressure.
3. High temperature.
4. Chemical reaction.
5. To solubility under ordinary conditions.

It follows that *if these causes be removed* the mineral matter can no longer remain in solution and must be deposited.

Deposition from solution takes place

I. *When the solvent escapes.*

Especially true of carbonic acid gas.
Origin of stalactites;* stalagmites (see plate V); stone pillars. Frozen cascades. (See plate VI.)
Origin of spring deposits of lime (tufas) by escape of CO_2; especially when sprayed at falls.
Terraced lime deposits.
Hardening of beach sands by ocean water containing CO_2.
Hardening of dunes of calcareous sands by CO_2 from the air.

II. *When the temperature is lowered.*

Hot water dissolves more mineral matter than cold.
Hot waters usually deep seated, and on approaching the surface cool and deposit.
Example: box from the Comstock mines.
Some hot-springs and geysers deposit tufas.
Quicksilver deposited in cool neck of retort.
When hot water is alkaline it dissolves silica and deposits siliceous sinter.†

III. *When the pressure decreases.*

All underground water is under hydrostatic pressure.
Pressure decreases as the water approaches the surface.
Coöperates with lowered temperature, in the case of waters from depths, to help fill cavities with mineral matter from depths.

IV. *When chemical reactions take place.*

Any reaction that causes precipitation.

* Stalactites, etc. By G. P. Merrill, Proc. U. S. Nat. Mus. XVII. 77–81. (Illustration.) Washington, 1894.

† Amer. Geol. Sept. 1897, 165. Weed, Folio 30, U. S. Geol. Surv., 1896.

Stalagmites of clear crystalline marble in Marengo cave, Crawford county, Indiana. The largest column is four feet, eleven inches high. (Blatchley.)

Stone pillars, or "frozen cascade," in Marengo cave, Crawford county, Indiana. (Blatchley.)

Examples: oxydation of iron in solution, and deposition of bog iron.
Probable relations to certain ore deposits.

V. *When solutions are allowed to stand long undisturbed.*
Example: geodes; some veins.

VI. *When there is a concentration of the water by evaporation.*
This is chiefly a surface phenomenon.
Efflorescence, or "alkali," thus produced (see p. 26); salt, borax, and alkaline lakes made in this way.

SALT LAKES.

Origin of the salt in salt lakes:

1. From the cutting off of an arm of the sea.
2. By the concentration of fresh water.
3. By some combination of the two.

1. *Cutting off an arm of the sea.*

Origin of the salt in the ocean: it was all originally in the hot rocks of the earth.
Water leached it out and concentrated it in seas.
Effect of the separation of any part, in dry climate.
Examples: salt spray pools on sea beaches.
Influence of an arid climate.
Waters of Red Sea, and of Mediterranean Sea, now denser than ordinary ocean water.
Cause of greater density of waters of the tropics.
Results of isolation depend on the relations of influx to evaporation.
A salt lake may wash out and become fresh.
San Francisco bay if cut off would wash out.
Sea of Galilee kept fresh by inflow, and outflow to Dead Sea.

2. *Concentration from fresh-water streams.*

River waters contain salt, epsom salt, and carbonate of lime, etc.
Waters flowing from sedimentary rocks all contain salt, etc.
If such waters evaporate, the salt is deposited.
If their basins overflow, the water stays fresh.

It is therefore a question of evaporation or of aridity.

The western tributaries of the Paraguay river are more or less salty because they flow from an arid region.
The eastern tributaries are fresh, owing to the greater rainfall.‡

‡ Buenos Ayres and the Provinces of the Rio de la Plata. By Sir Woodbine Parish, 233. 2d edition, London, 1852.

Caspian sea once had higher margins, but it is still fresher than the ocean.

Salt Lake, Utah, covers 2,000 square miles; it formerly covered 50,000 square miles and was fresh.

Freshness indicated by its former outlet.§

3. *Combination of the isolation of salt water and the concentration of fresh water.*

Salton Lake, formerly part of the Gulf of California, and since added to by the influx of fresh water from the Colorado river.

Association of salt and gypsum in salt lakes.

Salt can not be deposited in open sea; sea water is too fresh.

In sea-water gypsum is deposited only after eighty per cent of the water is evaporated, and salt after still further evaporation.

Gypsum not soluble in strong brine; hence it precipitates first.‖

In part of the Caspian Sea (Gulf of Karabougas) gypsum is now depositing.

Middle has beds of *mirabilite* (Glauber salt), sulphate of soda.*

Thickness of salt beds (maximum).

Syracuse, N. Y., Warsaw, N. Y., 65 to 318′; Kansas† 200′ thick.

Michigan 32′; Goderich, Can., at 964′–1180′ it is 14′ to 40′ thick. Orange Island, Louisiana, 1,865′. Spain, 300′—400′ in hills; Stassfurt, Germany‡ 4,794′+.

Explanation of great thickness of salt-beds.

Influx of sea water at high-tide and stonirms.

Lagôa de Freitas, Rio.

Influx due to evaporation in shallow marginal pools.¶

Interpretation of gypsum and salt beds.

Indicate salt lakes and arid climates at those places at the time of their deposition.

ALKALINE LAKES.

Alkaline lakes have been formed by the concentration by evapor-

§ Monograph I., U. S. Geol. Survey,

‖ Dieulafait, Pop. Sci. Monthly, Oct. 1897.

*Engineering and Mining Journal, Oct. 9, 1897, LXIV., 428.

†Gypsum deposits in Kansas, Amer. Geol., Oct. 1896, XVIII., 236.

‡ The salt deposits of Stassfurt. By H. M. Cadell. Trans. Edin. Geol. Soc., V., pt. I, 93. Edinburgh, 1885.

¶ Karamania, or .... the south coast of Asia Minor. By F. Beaufort. 2nd ed., 283. London, 1818.

ation of waters flowing over *igneous rocks* (in which *alkaline carbonates* predominate).

*Mono lake, California**; area 87 square miles in 1887, but varying.

Strong solution of salt and carbonate of soda (42.53 per cent. of the total constituents.)

Carbonate of lime, and borate of soda.

Old shore line 680′ above water (higher in glacial epoch), and hydrographic basin of 7,000 square miles.

Region arid mostly; the minerals will precipitate soon.

Owen's lake, California.

Water used to manufacture soda.

BITTER LAKES.

Bitter lakes are a further concentration of salt lakes.

Those containing bittern or liquor left after the deposition of salt.

Contain epsom salts, Glauber salt.

Such lakes cut on Suez canal.

They were below the level of the Red Sea.

The Dead Sea is a bitter lake.

BORAX LAKES.

Borax lakes are formed by the concentration of waters flowing from igneous rocks containing borax minerals.

Borax now made from the water of wells sunk in basins.

This water has flowed from igneous rocks and has been concentrated in lakes now dried up.

The depth to which waters penetrate the earth's crust.

Depth to which waters penetrate suggested by

I. *Hot waters.*

Earth's temperature increases downward.

Not uniform; varies with crust and place.

Average about 1° for 50′ in depth below constant line.

Reasoning from temperatures of hot springs.

Thermal springs of Bath, England=120° Fht.

If surface temperature of water were 40°, the additional 80° would be had at 80×50′=4,000′.

* 8th Ann. Rep. U. S. Geol. Surv., 287–299. Bul. 1.8 U. S. Geol. Surv. Russell's Lakes of North America, 83–89.

Method of procuring boring

Igneous

Igneous

Near volcanos hot water appears near surface — But often hot springs exist far away from volcanos —

Increase of temperature 1° per 50'

Hot springs of Arkansas, temperature

$$\begin{array}{rl} & 142^{\circ} \\ -40^{\circ} & \text{temperature at surface.} \\ \hline & 102^{\circ} \quad \text{above normal temperature} \end{array}$$

$102 \times 50' = 5,100'$ depth from which the water would have come, if the conditions were average.

II. *Depth to which rocks are altered by decay*

Suggests the depth to which surface waters penetrate.

In Brazil cuts of 100′ ; drill holes, 393′; mines, 400′*

Certain minerals (iron and copper sulphides) susceptible to change to carbonates, oxides, etc.

In mines some are found changed to depths of 600′, 1000′, and 1500′.†

These changes are produced by surface waters.

GENERAL RESULTS.

1. Meteoric waters *dissolve* rocks in one place and *deposit* them in another, or carry them to the sea.
2. They remove the soluble, and leave the insoluble.
3. They form cavities, caves, sink-holes, and channels.
4. Deposit dissolved materials in crevices, veins, and form surface accumulations.

* Branner, Bul. Geol. Soc. Amer. VII. 255.

† Penrose, Jour. Geol., 1894, II., 295.

RESUMÉ OF THE OPERATIONS OF CHEMICAL AGENCIES.

- **Chemical Agencies (not including those of high temperatures).**
  - ***Solution by***
    - CO_2 from the air.
    - Nitric acid in air from electric discharges.
    - Organic acids
      - CO_2 in soil.
      - CO_2 from organic decay.
      - Humic acids in soil from plants, and insects and other animals.
    - Increase of pressure.
    - Increase of temperature.

    → RESULTS
    - Residuary products
      - Soils.
      - Clays.
    - Alteration products
      - Gypsum from anhydrite.
      - Kaolin from feldspar.
      - Serpentine from olivine (or chrysolite).
  - ***Deposition by***
    - Escape of solvent (CO_2), forming stalactites, tufas.
    - Lowering of temperature; hot spring deposits, veins.
    - Decrease of pressure; vein deposits.
    - Chemical reactions; iron.
    - Standing of solutions.
    - Evaporation and concentration; salt, gypsum, borax, soda.

    → RESULTS: new minerals.

IGNEOUS AGENCIES, OR HIGH TEMPERATURES.

INTERIOR OF THE EARTH.

Evidences of the heated condition of the earth's interior.

I. Downward increase of temperature in wells and mines. 1° - 50'. (See page 120).

II. *Volcanoes* with their accompanying phenomena.
Explosions, steam, hot vapors and gases, molten rocks.

III. Geysers and other hot springs, bringing high temperatures to surface.

IV. Positions and characters of certain rocks, such as dikes and lava sheets, which appear to have been fused, and to be connected with masses penetrating the earth's crust.

Influence of interior heat on climate.

Not felt now; in 1 year would not melt 1 mm. of ice over the globe.

Its influence felt only during the early history of the earth.

THEORIES CONCERNING THE INTERIOR CONDITION OF THE EARTH.

I. *Fluid molten interior*, with hard crust.

Reasons for the theory.

Outflow of lavas and hot waters; high temperatures.

Objections to the theory.

Physicists show that there would be tides in such a globe.

It does not behave like a molten globe.

II. *Solid crust and center and molten layer between.*

Would answer geologic conditions.

III. *Solid as a globe of glass or steel.*

Because of behavior.

Objections:

Evidences of elevation and depression.

Our sedimentary rocks here are marine: Mt. Hamilton.

IV. *Solid throughout, except local pockets of molten rocks.*

Physicists and geologists can agree on this.*

Rate of increase of temperature downward.

Temperature of the ground surface varies daily and yearly.

This variation is due to outside or solar influence.

* Earth movements. By C. R. Van Hise. Trans. Wis. Acad. Sci. XI, 475, on "condition of the interior of the earth." Madison, 1898.

Interior of earth is very hot.

Earth warms at day + cools at night, + in case annual change - as well as daily -

Level of no change in the tropics is about 4′ deep ; at New York it is about 50′ deep.

Further north it is deeper.

Difference due to climatic fluctuations.

Below the line of uniformity the temperature rises.

The increase is constant, but the rate varies at different places, and at different depths.

On volcanic cones the high temperature is near the surface.

Comstock Lode, Yellow Jacket Mine.*

1° for every 28′ down to 3,000′.

Artesian wells increase 1° for about 50.′

North of England, 1° for 49.′†

New South Wales, 1° for 80′†

Schladebach hole, near Leipzig, 6,560′, 1° to 56′+

Idaho-Maryland mine, Grass Valley, California,‡ 1° to 70.′

Wheeling, West Virginia, 5,386′, Feb. 1897, 1° to 80–90′ in the upper half ; 1° to 60′ in the lower half.§

Calumet and Hecla copper mines, Mich., 1° to 224′, to a depth of 4,700′.¶

In Dakotas varying from 17½ to 45′ to a degree.‖

Variations may be due:

1. To varying conductivity of the rocks (which are not everywhere the same).
2. To varying conditions that produce high temperatures.

Temperature of 3,000° would fuse rocks.

$$\frac{3{,}000}{50'} \text{ descent for each degree.}$$

150,000′ = nearly 30 miles, the depth at which a temperature of 3,000° would be reached at this rate.

But 30 miles of rock increases pressure greatly and raises the fusing point.

Rocks expand on fusion.

Greater depth is therefore required to fuse them.

But this depth increases the pressure and raises fusing point.

* Becker. Monograph III. U. S. Geol. Surv. 229. Washington, 1882.

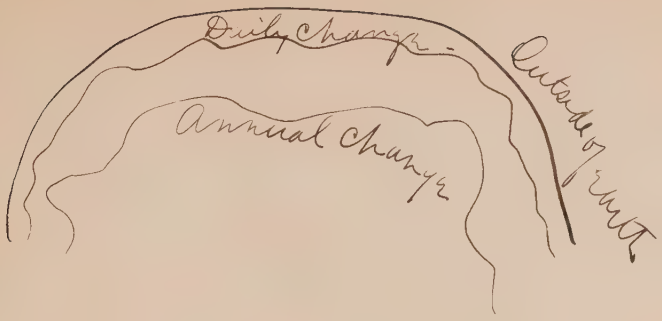
† Nature. 1896. LIV., 137.

‡ Lindgren, 17th Ann. Rep. U. S. Geol. Surv. II. 171. 1896.

§ Am. Jour. Sci. 1892. CXLIII, 234; School of Mines Quarterly, Jan. 1897. XVIII, 148 153.

¶ Am. Jour Sci. 1895. CL., 503.

‖ Geothermal data, etc. By N. H. Darton. Am. Jour. Sci. CLV. 161–168. New Haven, 1898.


Daily Change
Annual Change
Outside of crust

Difficulty of reasoning on the interior conditions of the earth.

We cannot reproduce the conditions.

Possibility of error regarding such temperatures and pressures.

Possibility of fusion being due to local relief of pressure, as in the case of the steam of geysers.

Lava supposed to come from a depth of less than 30 miles.*

Ridging of the crust by contraction of the globe.

Pressure at six miles makes rocks plastic and closes cavities.†

Volcanic activity is mostly confined to regions of breaking, slipping, faulting, and thrust.

In any case, the *igneous, or high temperature, phenomena are mostly deep seated*, though they manifest themselves at the surface.

VOLCANOES AND THEIR GEOLOGIC WORK.‡

Volcanoes are:

I. *Active.*

II. *Dormant* or extinct.

I. Active Volcanoes.

Definition: A volcano is usually a conical hill or mountain, with an opening (one or more) through which molten rocks, gases, and cinders escape from the hot interior to the surface. The mountain is the result, not the cause, and is not an essential part of a volcano.

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*J. L. Lobley, Geol. Magazine, April, 1897, 189.

†Flow and fracture of rocks as related to structure. By L. M Hoskins, 16th Ann. Rep. U. S. Geol. Survey, 859. C. R. Van Hise, same vol 593, Washington, 1896.

‡Volcanoes: what they are and what they teach. By J. W. Judd. New York, 1895.

Volcanoes of North America. By I. C. Russell. New York, 1897.

Characteristics of volcanoes. By J. D. Dana. New York, 1891.

The eruption of Krakatoa and subsequent phenomena. Report of the Krakatoa committee of the Royal Society. Edited by G. J. Symons. London, 1888.

The South Italian volcanoes. By H. J. Johnston-Lavis, Naples, 1891 (with bibliography).

The geology and extinct volcanos of Central France. By G. Poulett Scrope. London, 1858.

Aspects of the earth. By N. S. Shaler, 46–97. New York, 1889.

Volcanos, the character of their phenomena. By G. P. Scrope. London, 1862.

La face de la terre. Par E. Suess, tome I., 185-223. Paris, 1897.

The ancient volcanoes of Great Britain. By Sir Archibald Geikie, 2 vols. London, 1897.

If one should try expansive power of water + should find to his sat- 123
isfaction the rate from 35-200°-
But this is not invariable, as,
should the water be below 32°
it would arrive at freezing pt.
then his reasoning would not apply
Thus it is with reasoning on interior
conditions of earth-

When pressure is relieved from
underlying (igneous) rock volcanic
action ensues-

Cracks may be near surface, but
at depth of 6 miles rocks are -
pressed tightly together.

Volcanoes-

Difficult to say whether a volcano
is active or extinct as long period
may elapse between eruptions-

Formation of volca

Crust

ERUPTIONS.

A. *Conditions of eruptions.*

Supposed to be more or less affected by barometric pressure.

B. *Periodicity.*

Stromboli, once in 4 to 10 months.
Kilauea, in Hawaii, once in 8 to 9 years.

C. *Sequence of events.*

Rumbling.
Earthquakes.
Vapors.
Explosions.
Rise of lavas.
Overflow.

D. *Phenomena of eruptions.*

Quiet lava flows over the crater's edge.
Sheets on slopes or in valleys.
Cones of lava, or lava and "ashes," or cinders.
Lava from fissures on sides; due to hydrostatic pressure.
Pressure on the sides when the craters are high.
Height of South American craters.
Cotopaxi.*
Explosive eruptions scatter cinders and blocks.
Gases.†
Earthquakes.
Geysers.
Elevations.
Depressions.

E. *Materials of volcanic eruptions.*

1. *Lavas* and lava streams.
Rate of flow.
Size of streams.
Temperature.
Cooling.
Effect on drainage.
Dams.‡

*Travels amongst the great Andes of the Equator. By Edward Whymper. 126–127. New York, 1892.

†Observations on Mount Vesuvius, etc. By Sir William Hamilton. 164–7, 118-119, London, 1774.
Santorin et ses eruptions. Par F. Fouqui, 225, 232.
A description of active and extinct volcanos. By Charles Daubeny, 160, 375. London, 1826.

‡Observations on Mt. Vesuvius, etc. By Sir W. Hamilton. 12, foot-note. London, 1774.

Lava = molten rock -

Effect on topography.
Overwhelmed.*
The great lava floods of the northwestern United States. 150 000 sq. miles –
Formation of caves.

2. *Fragmental ejectamenta.*

Dust and "smoke." "sand" and "ashes." Some ascend 20,000'.† Tenguela 75 000'.
Lapilli.
Tuff if in water. Sedimentary rocks.
Pumice in windrows.‡
Blocks and other fragments blown from throat.
Thrown 12 miles.§
Bombs.
Mud produced by rains in ashes; by melting ice on high peaks.¶
Burying of Pompeii and Herculaneum under showers of fragmental material; Herculaneum 70' to 112' deep.‖

3. *Inclusions.*

Brought up from below.
Show relative age of eruptions.

Volcanic peaks (of construction) built up by ejectamenta.

Largest volcanoes are those of the Andes, 17,000 to 19,000' high.
Orizaba, Mexico, 18,314.'

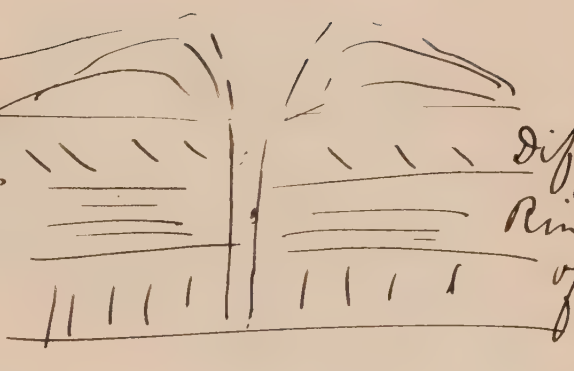
Ash and cinder peaks steeper than lava cones.

Angle of repose.
Mt. Hood, Oregon, 11,225'; Columbia river cuts 4,000' in its lava.
Mt. Tacoma, or Ranier (14,449').
Mt. Shasta (14,440') and vicinity.
Region between Lassen peak and Shasta, volcanic.

*Cadell on New Zealand volcanic zone. Trans. Edin. Geol. Soc. 1897, VII, 183.
†Whymper, Travels amongst the great Andes, 125, 141, 326-328, 330.
‡J. P. Iddings, Sci. Feb. 8, 1884, III, 144.
Across Vatna Jökul. By W. L. Watts, 105-8, 160, London, 1876.
§Hamilton's Observations, 49, note.
¶Travels amongst the great Andes of the Equator. By Edward Whymper, 126-7. New York, 1892.
On ashes about Vesuvius see Observation on Mount Vesuvius, etc. By Sir Wm. Hamilton, 34 note; 46; 94-95. London, 1774.

Smoke of volcano not made up of soot but fragments of mineral matter.

Inclusion- occurs when different Kinds of rock from the throat of the volcano are thrown up in eruption.



Impossible for fossils to be found in matter rock - nothing can live there but rarely often in inclusions they may be found -

Angle of repose for ashes & cinders broken materials 35-40°; for lava much lower; ∴ lava peaks are not so steep.

Lava cones are not so steep.

Angle of the slope of Mauna Loa.

VOLCANIC ROCKS.

Lavas, mostly dark colored.

On decay they often turn red, rusty brown, a purplish-red, terra rocha.

Some are glassy; *obsidian.*

Some "blistered" in appearance.

Small, angular, or rounded fragments.

Inclusions among ejectamenta.

Some lavas cool in columns, called *basaltic.*

Examples near Stanford University, Giant's Causeway (see Part III).

FIG. 11.—Horizontal basaltic columns on the island of Fernando de Noronha.

SUBMARINE VOLCANOES.

Peaks all over the sea-bottom, and many volcanic islands, lead us to suppose that many of them have been made by submarine eruptions.

Submarine lavas are the same as terrestrial ones.†

Santorin and Theresia Islands in Grecian Archipelago rose from the sea 237 B. C. (Sir Wm. Hamilton, 158–9.) (Daubeny, 229.) One of the Azores near St. Michael in 1628. (Sir Wm. Hamilton, 158–9.)

In 1783 one (Nyöe) 6 or 8 miles off Iceland. (Forbes, 286.) Island a mile in circumference, washed away and only a shoal in less than 1 year. (Daubeny, 224.)

In 1831 Graham's Island,* Sicily, 200′ high (a. t.) and 800′ above bottom; 3 miles around. Active 3 weeks.

Demolished in two years.

Bogosloff Island in Behring Sea.§

Volcanic islands all deeply wave-cut.

St. Helena cliffs, 1-2,000′.

Teneriffe, Fernando de Noronha.

DISTRIBUTION OF VOLCANOES.

By sides of deepest and largest oceans.

Wallace suggests that they "take away the foundations of the surrounding district" and thus make the neighboring seas deep.‡

VOLCANIC ACTIVITY ATTRIBUTED TO:

I. Presence of water (they follow oceans).‖

II. Contraction of the earth's crust where strains cannot be resisted.

III. Permanent lines of weakness of earth's crust.

The volcanic lines are approximately the same as formerly, as if these lines were fixed.

Why this is possibly true.

II. Dormant or Extinct Volcanoes.

I. Some volcanoes always active.

II. Some are quiet for years.

† Fouqué, Santorin et ses eruptions, XVI.

*A bibliography of Graham's Island is given in Johnston-Lavis' "South Italian volcanoes," 105–107.

§ I. C. Russell's Volcanoes of North America, 276–281; Kotzebue's Voyage of discovery, 1821. II, 180–1.

‡ The Malay Archipelago, 9. London, 1894.

‖ J. W. Judd. The eruption of Krakatoa. Rep. Krakatoa Com. of the Roy. Soc., 46. London, 1888.

III. Some are quiet for centuries.

We can therefore draw no line between the dormant and extinct ones.

Once extinct, a volcano crumbles rapidly.

Volcanic rocks make good soils.

Examples of extinct volcanoes.

* *Crater Lake*, southwest Oregon, surface, 6,239′ a. t.; 5–6 miles in diameter; no outlet; maximum depth of water, 2,000′; walls above water, 500′–2,200′; total depth of crater, 2,900′–4,200′.

Theories of its origin.

Marysville buttes, California.

The cones of central France.†

Ancient lavas:

Cascade range volcanic.

In Sierras on top of auriferous gravels.

Sheet near Stanford University; Frenchman's Lake, basaltic columns.

The Palisades of the Hudson, the edge of a lava sheet.

Giant's Causeway, Ireland: sheet covers 2,000 square miles.

Great sheet from northwest Wyoming down Snake river, 2,000 to 4,000′+ thick.

Dikes.

Lavas cooled in crevices.‡

Effect of temperature of rocks on size of dikes.

Stand out as walls.§

Laccolites.‖

Lavas intruded between beds.

Tuffs.

Fragmental ejectamenta, often covering large areas.

AGE OF VOLCANOES.

Rocks contain no fossils; why.

Age shown by relations to adjacent rocks.

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* Science, 1886, VIII, 179–182; 8th Ann. Rep. U. S. Geol. Survey, 157–8. Washington, 1889.

Crater Lake special map. By J. S. Diller. U. S. Geol. Survey, n. d.

† Scrope's Volcanos of France, 57–67. London, 1862.

‡ Open-air studies. By G. A. J. Cole. Plate VI I. op. 181. London, 1895.

§ Across Vatna Jökul. By W. L. Watts, 101, 109, 119, 153.-157. London 1876. On veins and dikes see Crosby in Tech. Quart. Dec. 1895, IX, 355.

‖ Geology of the Mountains. By G. K. Gilbert; Laccolites in Colorado. By G. K. Gilbert. Jour. Geol. IV. 816, Chicago, 1895.

The laccolitic mountain groups of Colo., Utah, and Arizona. By W. Cross. 14th Ann. Rep. U. S. Geol. Surv., 157-241. Washington, 1895.

ECONOMICS OF IGNEOUS ROCKS.

Fertility of soils.
Vesuvius and Etna covered with vines and towns.
Java and Japan thickly populated.
Sulphur deposits of Sicily and Italy.
Ores often concentrated next to dikes.
Use of basalt for road material at Stanford.
Tuffs and fragmental andesites do not hold water.
Examples: Frenchman's Lake; Sierra ditches.
Used for railway ballast in Arizona.
Pozzuolana used in making hydraulic cement.

GEYSERS.*

Geyser, a gusher. Forbes says it means "a rager"; it is applied to any noisy water in Iceland. (Forbes, Iceland, 230.)

Geysers are *periodically eruptive hot springs.*
Always hot.
Distribution.
Iceland.
New Zealand.†
Yellowstone National Park.

All in regions of former or recent volcanic activities.

Phenomena of eruption of the great geysers of Iceland remarkably like volcanic eruptions.

1. Cannonading—steam bubbles collapsing like singing of kettles.
2. Bulging of water and overflow.
3. Leaping upward of water, about 100′.
4. Escape of steam with noise.

Frequency diminishing.

1804, every hour; now, few days.
Dying out less marked in the Yellowstone region.

In Yellowstone National Park there are more than 3,000 vents.

Basin 3 miles wide, honey-combed.
Grand geyser temp. 150°, throws water 200′, and steam 1,000′.
Giantess throws a column 20′ in diameter 60′ high.
Smaller pits throw water 250′ high.
Some erupt for hours.

* Bibliography of geysers in Peale's 12th Ann. Rep. U. S. Geol. Surv. of the Territories. 1878, pt. II. 427–449. Washington, 1883. Geysers. By W. H. Weed. School of Mines Quarterly, July, 1890. XI. 289–306.

† A visit to the New Zealand volcanic zone. By H. M. Cadell. Trans. Edin. Geol. Soc. 1897. VII, 183–200.

THEORIES OF THE CAUSES OF ERUPTIONS.

Mackenzie's theory.* 1803-10.

Bunsen's theory.†

Downward removal of boiling point.

The greater the pressure, the higher temperature required.

Artificial geysers.

Relations of the overflow to eruptions.‡

CONDITIONS NECESSARY TO GEYSERS.

I. Igneous acid rocks, still hot above boiling point below, and cooler at and near surface.

II. Meteoric waters having access to hot rocks, or to vapors ascending from hot rocks.

III. Tube for escape of water and steam.

Effect of soaping geysers.

Resemblance of geyser eruptions to "bumping."

Bumping more marked in dense liquids.

Soaping increases the viscosity of the water.§

Geologic work of geysers.

Why cones are built around vents.

Relief of pressure and cooling.

Fire-hole fork of Madison River *deposits silica.*

Petrifying of trees, twigs coated.

Gardiner's river deposits travertine in terraces.¶

HOT SPRINGS.

The high temperature of hot springs, caused by surface waters coming in contact with hot rocks before the waters emerge.

When the conditions of supply and emergence are favorable, geysers are formed, but otherwise only hot springs.

In most cases hot springs never have been geysers, and there is little or no evidence of hot rocks about them.

Terraces formed by hot springs.

Method of formation.

* Travels in the Island of Iceland. By Sir George Steuart Mackenzie, 2d ed. London, 1812, 226–229.

† Heat as a mode of motion. By J. Tyndall. 168. New York, 1888.

‡ Some conditions affecting geyser eruption. By T. A. Jaggar, Jr. Am. Jour. Sci., May, 1898, V 323-333.

§ Experiments with an artificial geyser. By J. C. Graham. Am. Jour. Sci., Jan. 1893. CXLV, 54. Soaping geysers. By Arnold Hague. Trans. Am. Inst. Min. Eng., 1889. XVII, 546.

¶ Some geological causes of the scenery of Yellowstone National Park. A. R. Crook. Amer. Geologist, Sept., 1897, XX, 159–167.

A visit to the New Zealand volcanic zone. By H. M. Cadell. Trans. Edin. Geol. Soc., VII, 192. Edinburgh, 1897.

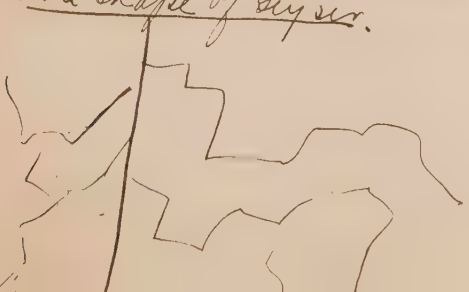
Bunsen studied Geysers in Iceland + came to this conclusion:

Rocks get very hot. Steam presses in water channel + causes over flow at the mouth.

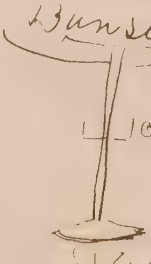
Geysers are really cracks + crevices in the rocks, of all shapes, forming an outlet for the steam.

Water soaks down + meets these hot rocks. Water will boil at 212° on surface, but the greater the pressure the higher temp. it takes to form steam. The bubbles of steam down at bottom rise + keep collapsing as rise to surface; this causes rumbling

Possible shape of Geyser.



Bunsen's Theory of Geysers



Charcoal

Possibility of heat being caused by .

I. Chemical reaction.
II. Burning coal.

Hot Springs vary little in flow; they are deep-seated.

Supposed medicinal properties of hot springs.*

EARTHQUAKES.†

Earthquakes are vibrations or jars, rock or earth-waves propagated through the earth's crust. These are produced by concussions in the crust.

The science of earthquakes called *Seismology*.

Concussions may be caused by :

I. Snapping of rocks under strain.
II. Slipping of rocks on each other. Readjustment.
III. In vicinity of volcanoes, by explosions within, possibly the forming and collapsing of steam. To understand earthquakes, it is necessary to study propagation of waves through rocks under complex conditions of various structures, compositions, and strains.

Wherever faults are common in the rocks, earthquakes must have occurred, even though they may now be extremely rare.

Every readjustment must cause jars.

Note folded and faulted *Appalachians ;* faults 10,000′+; Scotland ; Alps ; faults of California.

Irregularity of sea bottom and possible slips there.

Hence, jars are to be expected along lines of weakness and readjustment. Volcanic regions are regions of readjustment.

But *the wave travels at different rates* owing to the difference in the conductivity of rocks.

In loose sand, 984′ per second ; sandstone, 7,400′ per second ; granite, 9,200′ per second.

Explosions at Hellgate, New York, observed in Boston, Mass., gave a rate of transmission of 4,500′ to 20,000′ per second.

The form of the wave at the surface is determined by these differences in conductivity.

*The mineral waters of Arkansas By J. C. Branner, 10. Little Rock, 1892.

† Les tremblements de terre. Par F. Fouqué. Paris, 1889.

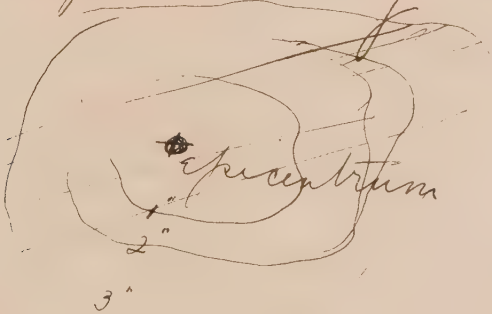
Great Neapolitan earthquake of 1857. The first principles of observational seismology. By Robert Mallet. 2 vols. London, 1862.

Transactions of the Seismological Society of Japan. Vols. I to XVI, 1880 to 1892.

The Charleston earthquake of August 31, 1886. By C. E. Dutton. Ninth Ann. Rep. U. S. Geol. Surv. 203–528. Washington, 1889.

La face de la terre. Par E. Suess, Tome I, 95–137. Paris, 1897.

Faults = rocks slipping upon each other
Every time a fault occurs an
earthquake is the result =
In Calif. often earthquakes
are confined to very limited area



Epicentrum.

Location of epicentrum.
Coseismal lines. Originate underneath Ground-
Form of coseismal lines found by time observations.

Focus.

Depth of focus.
Charleston earthquake 12 miles.*
Some about 4 miles below the surface.

Displacement.

Amount of displacement of an earth particle is seldom more than 3 or 4 millimeters; some only a fraction of millimeter. (This does not refer to vibrations of swinging objects.)

Form of movement.

Shown by seismograph.†
Comments on "direction of the movement."

Influence of position in relation to focus

At Riobama in 1797 bodies were thrown several hundred feet in the air.

Reflex action.

Effect in mines and at surface.

Sometimes not felt as strongly in mines as on top.
Cause of variation.

Frequency.

Varies with locality; two a day in Japan.
Common in volcanic regions.
California a region of faults and extinct volcanoes.

Limits of area.

Sometimes shocks are felt over areas of thousands of square miles. In California often over a few miles only.

RESULTS OF EARTHQUAKES.

Fissures and faults.

Japanese earthquakes and faults.‡
Sonora, Mexico, shock in 1887, crack 100 miles; fault 8′.§
Arizona.‖

* Dutton. Ninth Ann. Rep. U. S. Geol. Sur. 311. Washington, 1889.

† See records in the Journal of Seismology.

‡ On the cause of the great earthquake in Central Japan, 1891. By B. Koto. Jour. of the College of Science. Imp. Univ. Japan. V, pt. IV, plates. Tokyo, 1893.

§ Science Aug. 12, 1887, X 81.

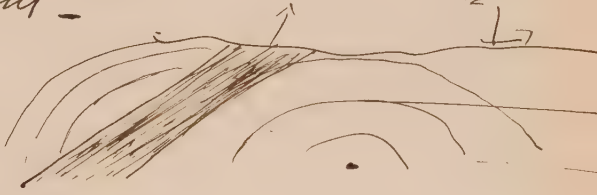
‖ Kemp's Ore deposits, 15. New York, 1893.

Epicentrum = surface central pt. of earthquake.

Focus = pt. underneath surface where earthquake starts.

Movements of earthquakes usually very complex -

Rocks have different conductivity, thus the rates of motion of earthquake waves are very different -



Pts. in Cal. are very much faulted, ∴ more earthquakes in Cal -

Once a fault line is established in earth's surface, that fault causes other faults in vicinity -

New Zealand, 1848; 60 miles long; 18 inches throw.
New Madrid, Missouri, chasm opened.
Inyo, California, shock of 1872; crack 40 miles long; fault 25′.*
The deluge of the Bible supposed to be due to the inundation of the lower Euphrates by an earthquake.†

Joints in rocks.

Rocks bend slowly, but snap when under strain or from a sudden jar.

Earthquake waves (improperly called tidal waves) may be due to sudden lifting or lowering of water surface.
Destruction wrought by wave. Examples. Japan,‡ Lisbon.

Landslides if in wet weather.
Lakes and pools formed.
Slides dam streams; breaking of such dams is dangerous.
Case in India in 1897.

Drying up of springs.

Water turned into other channels.

Terrors of earthquakes due to the fact that there is no means of predicting the time or nature of the shock, and to the instability of the earth, which is the very type of stability.
No courage or skill can prevent them.
California must always be an earthquake region.

PRECAUTIONARY MEASURES.

Japanese houses built of wood.
Earthquake houses placed on balls.
Destruction here really very small.

Destruction of life mostly caused by the falling of walls of houses.
Catania, Sicily, earthquake in 1693—100,000 killed.§
Lisbon earthquake, 1755, killed 60,000, but largely by wave on wharves.
Japan earthquake of 1896 killed 26,975, mostly by wave dashing upon the shores.
Riobamba. (See Whymper.)

* Nature, Nov. 8, 1883, XXIX, 45.

† La face de la terre. Par. E. Suess, tome I., 25–95. Paris, 1897.

‡ Across America and Asia. By R. Pumpelly. 107. London, 1870. National Geographic Mag. Sept. 1896, VII. 285–9; 310.

§ Sir W. Hamilton's Observations. 59. London, 1774

In possibility of predicting earthquakes.

CHANGES OF LEVEL.

Changes of level, either *elevation* or *depression*, often *accompany earthquakes* and *volcanic eruptions*.
Sometimes abrupt, as at St. Thomas, W. I.
Sometimes quiet, slow and uniform.
In any case they are due to agencies connected with the interior condition of the earth.

EVIDENCES OF ELEVATION.

I. Dead marine organisms, or their skeletons, on dry land.
II. Work of marine animals on land.
III. Work of waves (either constructive or destructive) on shore lines now out of the reach of waves.
IV. Human records.

I. *Dead marine organisms or skeletons on land.*

Coral reefs of St. Thomas.
Raised reefs of Mombasa, East Africa.*
Raised reefs of Cuba; 1000′ to 1100′ a. t.
Raised reefs of Peru; 3000′ a. t.†
Fossils (oysters and sea urchins) on basaltic columns.
Shells of Baffin Land.‡ El. 270′ to 300′.

II. *Work of Marine animals on land.*

Sea urchin holes about the bay of Rio de Janeiro, 3′ a. t.
Pholas holes with shells at Purissima.
Pholas and worm tubes on Page Mill road.
Lithodomus of the temple of Jupiter Serapis, Italy.

III. *Wave work* (either constructive or destructive) *now beyond the reach of waves.*

Terraces and old beaches at Santa Cruz.
San Pedro Hill, near Los Angeles, terraced.
Santa Catalina Islands.
Drift timber on Hudson Bay above tide.§
Terraced fjords of Norway.
Raised beaches of Baffin Land.‖

IV. *Human records.*

Scandinavia rising north of Stockholm at the maximum rate of 5′ to 6′ per century.

*Gregory's Great rift valley, 45, 51, 55. London, 1896.

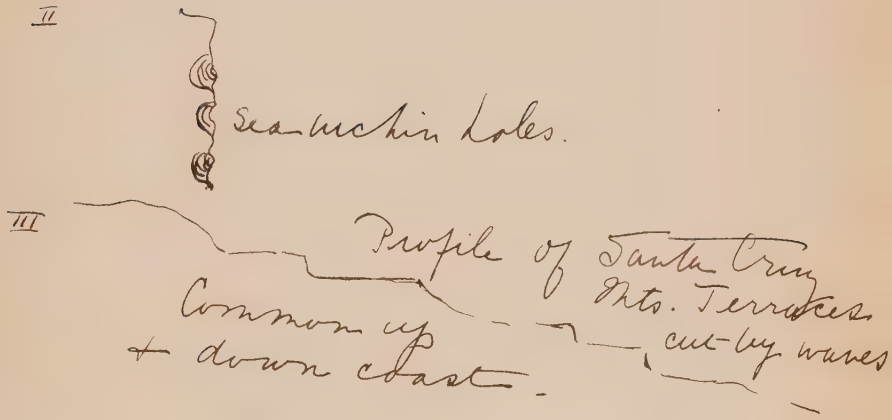
†A. Agassiz. Proc. Am. Acad. Sci. XI, 287. 1876.

‡Elevations of Baffin Land. By T. L. Watson. Jour. Geol. 1897. V. 17–33. Partial bibliography for N. Amer., 32–33.

§Robert Bell, Am. Jour. Sci., Mar. 1896, CLI, 219–228.

‖Evidences of recent elevation of the southern coast of Baffin Land. By Thos. L. Watson. Jour. Geol., 1897, V. 17–33.

has. Darwin found a little island
Conception, near Chili, which
had been elevated just few
days before - Molluscs
beginning to decay -



Evidences of Depression.

Evidences of depression are more difficult to see because the land surface goes beneath the water; often it is re-elevated and uncovered.

I. *Land plants in place covered by marine deposits.*

Peat below tide on the Bay of Funday.*

Stumps in La. and in N. J.

In N. J., cedar stumps on beach reached by salt water.†

II. *Corals found (in wells) below depth at which they live* (150′).

Recent boring (Oct., 1897) in Northeast Australia 698′ in coral.‡

III. *Submerged valleys.*§

Valleys can be cut in certain forms only on land.

Firths of Scotland.

Fjords of Norway¶; coast of Maine.‖

Filled-up bays of Oceanside, Calif ; of New Jersey.

Drowned valleys of the west coast of U. S.**

IV. *Distribution of plants and animals.*

Identity of Sta. Catalina Island plants with those of the mainland.

Elephants' teeth found on Santa Rosa and on mainland.

Elephants on St. Paul island show sinking to disconnect it from mainland.

Trees in Muir inlet exposed at low tide.††

Great Britain's former connection with Europe.‡‡

Wallace's work on Malay archipelago.

Prof. C. H. Gilbert's work on the distribution of Pacific coast fishes. (Fresh-water fishes.)

Case of the Isthmus of Panama.§§

*Canadian Naturalist. 2nd ser. 1881, IX, 373.

†Ann. Rep. State Geol. of N. J., 1885, 93.

‡Nature, Mar. 24, 1898, LII, 494–5; Nature, July 7, 1898, LIII, 221.

§T. Codrington on submerged rock valleys in South Wales, Devon, and Cornwall. Quar. Jour. Geol. Soc., Aug. 1898. LIV., 251–278.

¶Fjords and submerged valleys of Europe. By W. Upham. Amer. Geol., Aug. 1898, XXII, 101–108.

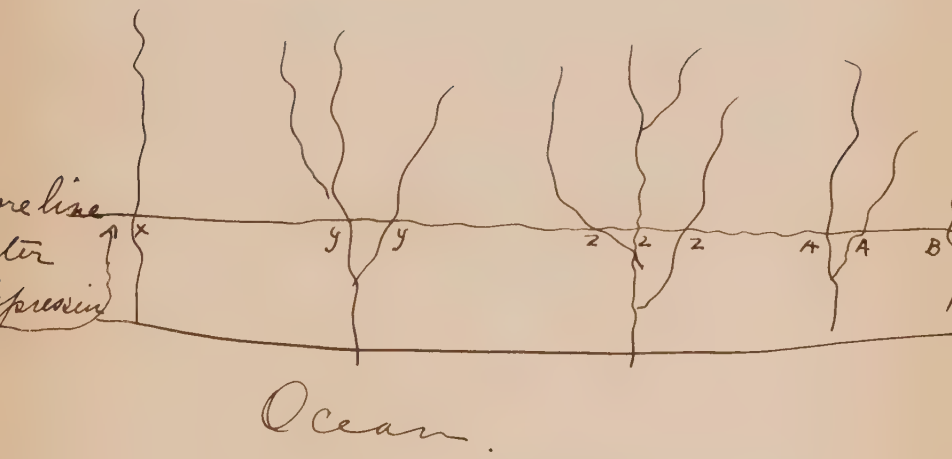
‖Henry Gannett, Physiographic types. Folio 1, Physiography, Topographic Atlas of the U. S. Washington, 1898.

*The submerged valleys of the coast of Calif., etc. By George Davidson. Proc. Calif. Acad. Sci., 3d ser.: I, 73–101. San Francisco, 1897.

††Reid. 16th Ann. Rep. U. S. Geol. Surv. I, 440. Washington, 1896.

‡‡Wallace's Malay Archipelago. 8, 10–14. London and New York, 1894.

§§The geol. history of the Isthmus of Panama. By R. T. Hill Bul. Mus. Comp. Zoo. 1898, XXVIII, 266–270.


X
Y
Y
Z
Z
Z
A
A
B
Ocean.

V. *Historical records.*

Scania, South Sweden, streets below water.
Dunkirk fields.
Tilting of the region of the Great Lakes.
Observations, from 20 to 37 years, show changes from .061 to .239 feet.*
Spanish building at the mouth of the Mississippi river.†

Distribution of changes.

No part of the earth's crust is quiet.
Some parts change more rapidly than others.

RATE OF CHANGES.

The rate must necessarily vary greatly. Darwin mentions flat island of Sta. Maria raised at a jump, and he found on land "gaping, putrefying mussel-shells, still attached to "the bed on which they had lived."‡ S.W. of Chili.
St. Thomas raised at a jump, bringing up live corals to perish on the beach.
Gilbert cites tilting about the Great Lakes at the rate of 0.42′, a century in 100 miles.§
Norway north of Stockholm, rising 5′ to 6′ per century.
New Jersey coast, Long Island to Cape May sinking 2′ per century.

CAUSES OF ELEVATION AND DEPRESSION.

Theories.

I. Internal heating and cooling.
II. Denudation and deposition.
Theory of isostacy.¶
III. Change of physical condition of the interior.
Contraction of rocks on changing to crystalline condition.
IV. Loss of water, air and gases.

*Modification of the Great Lakes by earth movement. By G. K. Gilbert. National Geogr Mag., Sept. 1897, VIII, 233–247.

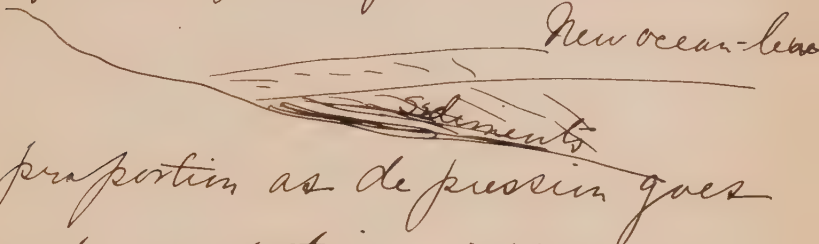
†Nat. Geogr. Mag. VIII, 352.

‡Geological observations. By Chas. Darwin, 216.

§National Geogr. Mag. VIII, 245. Washington, 1897.

¶The great valley of California, a criticism of isostacy. By F. L. Ransome. Bul. Geol. Dept. Univ. Calif., I, 371–428.
Earth movements. By C. R. Van Hise. Trans. Wis. Acad. Sci. XI. Theory of isostacy on pp. 469–475 and foot-note; 478. Madison, 1898.

. Great thickness of sediments in different pts. of the world.



In proportion as depression goes on, sedimentation will go on. Movements of earth's crust go on continually, often not susceptible!

In 3000 yrs. Gilbert says Niagara River will cease to run; drainage of G. Lakes will turn into Miss. R. as in Glacial epoch.

ORGANIC AGENCIES OR THE WORK OF ORGANISMS IN GEOLOGY.

Organic agencies are *destructive*, *preservative* and *constructive*.

I. *Destructive organic agencies* are those that produce or hasten rock decay, such as organic acids.

II. *Preservative agencies* are those that protect rocks from destruction, such as seaweeds and mollusks that prevent waves from cutting the shores.

III. *Constructive agencies* are those that form new rocks, such as peat from plants and limestone from coral.

I. DESTRUCTIVE ORGANIC AGENTS.

Decay of plants and animals produces humic acids that attack minerals.*

Roots of plants.

Roots etch the rocks.

Experiments on marble slabs.

Roots pry rocks apart.

Ivy prying boards.

Sidewalks lifted by the roots of trees.

Water follows down roots.

(Luther Wagoner of San Francisco tells me of several roots of pine, or some other conifer, 3/8 of an inch in diameter, found 60′ below the surface of the ground in a mine in Nevada county, California; rocks decayed.)

General tendency of plant roots to break up rocks and minerals.

The decay of roots produces destructive organic acids.

Liverworts.

Sea-urchins bore holes in the hardest rocks.

Example: quartz-porphyry of Santo Aleixo.

Boring mollusks, Lithodomus and Pholas, bore rocks.

Examples: shores of Santa Cruz, Monterey, and the coast.

Burrowing insects.

Ants of the tropics.† Hastens decomposition.

Worms.‡

* A. A. Julien, Proc. A. A. A. S. 1879, XXVII. 324.

Rock, rock-weathering, and soils. By G. P. Merrill, 190, foot-note. Merrill. Jour. Geol., 1895, IV. 856.

† Decomposition of rocks in Brazil. By J. C. Branner. Bul. Geol. Soc. Amer. 1895. VII 295.

‡ Vegetable mould and earthworms. By Chas. Darwin. New York, 1882.

Full grown, range two & one-half acres in extent in a night — by ants.

I Clock packed up in excelsior from May 1st to Oct. Marble petrifies rough when so packed, & whenever excelsior touched (marble) acids etched lines.

Roots of plants attack rocks, & dissolve mineral matter with their acids.

Just as soon as a rock cracks its destruction assured.

Rounded outlines of hills in Cal. The roots of trees here much deeper than in the east, & take moisture from much greater depth. Has more water ways than in the east & more destruction to hills.

Animals breathe out carbon dioxide &

Other burrowing animals.

Rabbits, squirrels, ground-hogs, gophers, let in water and gases.

Crayfish on canals and rivers.

Some cause levee breaks of the Mississippi.

II. PRESERVATIVE WORK OF ORGANIC AGENTS.

Protection of coasts by animals.

Corals and mussels.*

Protection by plants.†

Nullipores. Seaweeds.

Seaweeds.

Mangrove swamps of the tropics,‡ 5 to 20 miles wide.

Bamboos of the Amazonas.

Bushes generally along stream and lake shores.

Water hyacinth in Florida helps to check streams, and to check scour and deposit.§

Plants on dunes prevent the blowing of sand.

Roots of willows on canals and creeks prevent wash.

Turf protects soil from wash, and rocks from exposure and decay.

Forests on mountain slopes prevent snow slides and land slides.

Forests generally prevent the rapid melting of snow in the spring; prevent rapid flow of rain waters, and thus decrease floods and erosion.

III. CONSTRUCTIVE ORGANIC AGENTS.

Deposits.

Plants.
- *Carbonaceous.* sphagnum, peat, lignite, coal, oil, gas.
- *Sulphurous.*
- *Ferruginous:* iron.
- *Nitrogenous:* nitre.
- *Siliceous:* diatoms (algæ), chert, ooze, silicified wood.
- *Calcareous:* nullipores, algæ.

Animals.
- *Calcareous:* corals, shells, bones, ooze.
- *Siliceous:* sponges, radiolaria.‖
- *Phosphatic:* guano, bones.

* Across America and Asia. By R. Pumpelly. 188. London, 1870.

†The conservative action of animals, etc. By W. A. Hardman. Proc. Liverpool Geol. Soc. 1889. V. 46–51.

‡Freshwater morasses. By N. S. Shaler. Tenth Ann. Rep. U. S. Geol. Surv. Part I, 291. Washington, 1890.

§The water hyacinth . . . . in Florida. Bul. 18. Bot. Div., U. S. Dept. Agr. Washington, 1897.

‖Geikie's Text-book of geology, 439. 3d ed. London and New York, 1893.

Organic agencies = animals + plant

Mangroves
form a network
+ protect shores

Plants as Constructive Organic Agents.

CARBONACEOUS DEPOSITS.

The rocks of carbonaceous plant origin are as follows:
(Note relations of *oxygen* and *carbon*)

Rocks of carbonaceous plant origin.		Oxygen. Percentage.	Carbon. Percentage.
	(Wood	44	49.)
I.	Peat	30–40	59
II.	Lignite	20–35	68
III.	Bituminous coal	10–15	81
	Anthracite coal	1½–2½	95
IV.	Graphite	0	100
V.	Diamond	0	100

Petroleum, *asphalt*, *gas*, and related carbonaceous minerals, are derived by distillation from organisms, but probably not from any one kind.*

The carbonaceous parts of rocks are derived from either plants or animals—chiefly from plants.

Wood contains 49% of carbon and 44% oxygen (+ 6% of hydrogen).

I. *Peat.*†

Peat is woody matter that has lost oxygen, and is thus altered part way to lignite.

Antiseptic property of peat prevents decay.

Peat made of mosses (*Sphagnum*), grows in marshes, and floats on, and fills, shallow ponds.

Moss dies below, grows above; generations of plants.

Changes at bottom to brownish black, cheese-like muck.

Penetrated by roots of plants growing over surface.

Cover large areas, 5′ to 50′ thick.

Rate of growth varies with conditions; 1′ in 5 to 10 years.

Some of the European bogs have grown in 1800 years, and have stumps, roads, coins, etc., beneath them. These bogs have grown from one inch to several feet per century.

Extent.

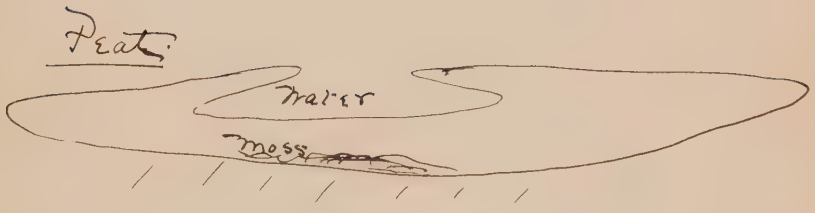
Cover one-seventh of Ireland.‡

Moss of Shannon, Ireland, 50 miles long and from 2 to 3 wide.

*The production of an asphalt by the distillation of a mixture of fish and wood. By W. C. Day. Proc. Am. Phil. Soc. 1898. XXXVII, 171.

†The formation of peat-mosses, by Hampus von Post, Bul. Geol. Institute of the University of Upsala, 1892–3, I, 284; G. Hellsing. II, 345.

‡Geikie's Text book, 480, 3d ed., London and New York, 1893.


Peat
Water
Moss

Dismal Swamp of Virginia and North Carolina contains 300 square miles of peat bog.

Solway moss in northwest England, near Scotland, 7 miles across.

In Norfolk, England, 500 square miles of peat; clay and sand separate the beds.

United States and Canada to Montana; New England.

Bursting of peat mosses or peat bogs.

Become waterlogged, burst, and flow.*

II. *Lignite.*

Lignite, or *brown coal*, is common in rocks of Tertiary and Cretaceous age.

Appears to be a further change of peat.

Change takes place very slowly and cannot be observed.

Evidences of peat origin of lignite.

I. Spores found in lignite like those in peat.
II. Plant impressions the same in peat and lignite.
III. Intergradation of peat and lignite.
IV. Clays beneath lignite contain roots like those penetrating the clays beneath peat.
V. Experimental demonstration. †

Interbedding of lignite and sediments.

Sections often show several beds of each.

Must have been flooded; or if there are marine fossils, the peat moss must have been covered by the sea.

III. *Bituminous coal.*†

Intergradation of lignite and bituminous coal.

Change very slow; not in man's time.

Coal not derived from marine plants, for fucoids contain 75–80% water.

Coal usually has clay below, with roots penetrating it. Stumps found standing.

Sediments interbedded with the coal show changes by submergence and new growths.

Splitting of coal beds accounted for.‡

Anthracite coal.

Changed form of bituminous coal.

Plants preserved as coal in some cases.

Relations of the anthracite fields of Pennsylvania to the bituminous ones of the same state.

*Nature Jan. 14, 1897, LV. 254–6; Jan. 21, 1897, LV, 268.

†See abstract of work of Adams and Nicholson, Science Jan. 21, 1898. New series VII, 83.

‡Lapparant, Traité de géologie, 841, Paris, 1885.

Peat bogs are composed of accumulations of dry leaves, 157
moss etc.
Peat is the origin of coal.

Sandstone
Coal
Shale

Plants that produce peat reproduce by spores. These spores occur in lignite showing peat origin.
Enormous pressure put upon peat, with rather high temperature & in process turned into coal.

Sandstone
lignite
Clay
Sandstone
lignite
Clay

Fossils found in coal are usually marsh fossils.

Peat - lignite - bituminous coal - anthracite coal - graphite - diamonds.
Greater pressure on coal causes difference in coal itself.

Change in the upper ends of synclines at Forest City, above Carbondale.
Ultra change of Rhode Island anthracite.

Theories advanced to explain origin of coal.

1. *Marine plants.*
   Marine plants have no wood, but cellular tissue only.
2. *Blown into lakes from the land.*
   Too widespread; area of North American coal fields.
3. *Floated timber of deltas.*
   Too much and too widespread; the coal beds are of rather even thickness; drift wood irregular and mixed with mud.
4. *Timber floated into the sea.*
   Stumps beneath the coal are rooted in place.
5. *Peatbog theory of origin now accepted.*
   Carbon from the air.
   Renewed from the crystalline rocks.
   Air not necessarily overcharged.*

IV. *Graphite.*

Graphite seems to be produced by a still further change of coal.
Too much changed to be available for fuel.
Changed in some cases by excessive heat.
Found in the oldest rocks.
Origin of the graphite found in pig-iron; derived from coal.

V. *Diamonds.*

Diamonds are crystalline forms of carbon, probably formed by change of graphite by pressure and heat. Graphite found in the diamond matrix of Brazil.†

Drift timber.

Enormous quantities of drift timber washed down by freshets.
Rafts in rivers; common in delta regions.
Atchafalaya, La., raft 10 miles long by 700′ wide, 8′ thick; 50 years' accumulations.
Floating islands of the Amazonas and of the Paraguay.
Water hyacinth of Florida.‡

*Claypole, Trans. Amer. Microscopical Soc. 1897. President's address.
†O. A. Derby, Jour. Geol. VI., 121-146, Chicago, 1898.
‡Bul. 18, U. S. Dep. of Agriculture, Division of Botany. Washington, 1897.

SULPHUROUS DEPOSITS FROM PLANTS.

Certain bacteria extract sulphur from sulphuretted water (sewage works and factory effluents) and store it up as globules, known to engineers as "sewage fungi."*

In hot springs in Japan;† temperature 154° to 157° Fhr. Only in water with hydrogen sulphide.

FERRUGINOUS DEPOSITS FROM PLANTS.

Iron carried in solution in streams as carbonate, loses CO^2 through the agency of bacteria, and ferric oxide is precipitated.

NITROGENOUS DEPOSITS FROM PLANTS.

Nitre or saltpeter, formed by nitrifying bacteria.‡

SILICEOUS DEPOSITS FROM PLANTS.

Diatoms are low forms of plants (algæ); live in salt or fresh water.
Abundant in fresh warm waters of Yellowstone Park.
Temperatures up to 185° Fht.
Deposits there 3′–6′ thick; called "sinter."
Silica extracted from the water.

Deposits consist of accumulations of skeletons.
Marine diatom beds at Santa Cruz 200′ thick.
Monterey 50′ thick.
Crow's Landing, California.
Near Stanford University, on the Page Mill road.
In Nevada 200–300′ thick.

Rocks of diatoms§ are earthy like chalk, harsh to the touch, will polish metals of smooth surface.

Often in swamps beneath peat.

Called *tripolite*, tripoli powder, infusorial earth.

Siliceous sinter of the Yellowstone National Park formed by low forms of plant life.‖

Silicified wood is not properly a siliceous deposit made by plants, but a replacement of wood by silica from solution.

CALCAREOUS DEPOSITS FROM PLANTS.

Nullipores are coral-like calcareous masses growing in salt water.

They help build up coral reefs and coral sand-beaches.

*Bennett and Murray's Cryptogamic Botany, 454. London and New York, 1889.

†Amer. Naturalist, June, 1898, XXXII, 456–457.

‡Microbes, ferments and moulds. By E. L. Trouessart. 121–122. International scientific series. New York, 1892.

§On diatoms, see Zittel; Paleontologie, Pt. II. 3 *et seq.* (French edition.)

‖W. H. Weed, Ninth Ann. Rep. U. S. Geol. Surv. 650–676. Washington, 1889.

Sand on sea-beaches = silica.
Glass is formed from "
diatoms are an important agent
in formation of rocks—

Other Calcareous algæ contribute to marine calcareous deposits.*

Calcareous tufas of Great Basin formed through the agency of low plant life.†

One calcareous spring in Yellowstone Park (Mammoth Hot Spring); deposits made by algæ.‡

Some calcareous oölites are lime secretions of algæ.§

Animals as Constructive Organic Agents.

A. CALCAREOUS ROCKS MADE BY ANIMALS.

I. Corals, worms whose skeletons are attached.

II. Shells of microscopic marine organisms living at or near the water's surface: foraminifera.

III. Shells of univalves (gasteropods), bivalves (lamellibranchs), worms, echinoderms, crustaceæ, and all animals having calcareous skeletons, whether vertebrates such as fishes, or invertebrates such as crinoids.

*I. Coral Reefs.***

Importance of the subject.

I. Large areas of the globe covered by coral reefs and islands. Australian reef 1,250 miles long by 10 to 90 miles wide.

II. Coral makes much of the lime rock of the earth.

Coral rocks are formed from the skeletons of polyps.

Animals are soft, gelatinous, often transparent, of various colors.

Radiate structure, with tentacles.

Carbonate of lime deposited in the lower part, which is fixed.

Form and deposition of the lime by polyps are vital functions, and not subject to will.

Growth of reef is produced by growth of these deposits.

Forms of corals.

I. Loosely branching.

II. Solid, spherical or hemispherical.

III. Tabulate.

*Proc. and Trans. Nova Scotia Institute of Sci. IX, XCII–XCIII, 1897.

†I. C. Russell, Bul. 108 U. S. Geol. Surv., 94–95. Washington, 1893.

‡W. H. Weed, Ninth Ann. Rep. U. S. Geol. Surv , 628–649. Washington, 1889.

§A. Rothpletz, Amer. Geol. X, 1892, 279–282. For bibliography of oölites see: The Bedford oöltic limestone of Indiana. By T. C. Hopkins and C. E Siebenthal, 21st Ann Rep. State Geol. Indiana, 397–410. Indianapolis, 1896.

**The structure and distribution of coral reefs. By Charles Darwin. 3d ed., London, 1889.

Corals and coral islands. By James D. Dana. 3d edition, New York (1890).

On the structure and origin of coral reefs and islands. By John Murray. Proc. Roy. Soc. Edinburg, 1880, X, 505.

The islands and coral reefs of the Fiji group. By Alexander Agassiz. Am. Jour. Sci. Feb. 1898. CLV, 113–123.

Reproduction.

I. By eggs having power of locomotion, and floating away in the water till they attach themselves to the rocks.
II. By branching or budding.

Conditions of coral growth.

I. Temperature at or above 68° Fht.
II. Depth, 150′ and less; most favorable at 50′ and less.
III. Clear salt water.

Effect of elevation, mud, and volcanic ashes.

IV. Constant change of water: necessity of lime and oxygen.

Forms of coral reefs.

I. Fringing: join the land.
II. Barrier: form barriers between sea and land.
III. Circular: approximately circular; enclose water; sometimes enclosed lagoons fill up.

Theories of reef formation.

I. *Subsidence theory of Darwin.*

1. Intergradation of reef forms.
2. Actual subsidence of some existing islands.
3. Depths at which reef rocks are found.
   Bore hole sunk Oct., 1897, at Funafuti, northeast Australia, 698′ in coral and no bottom.*
4. Elevation of some reefs.
   For depression is as common as elevation.

II. *Theory of submarine peaks.*

Conditions.

I. That the coral polyps take possession of submarine peaks.
II. That when the depth is too great, accumulations of microscopic organic remains build up the peaks till they come within the reach of the corals.

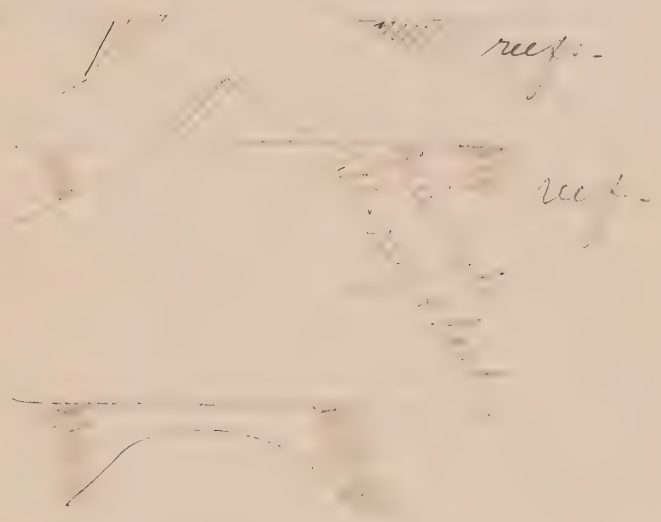
Murray thinks atolls grow larger by building beyond the growing depth.
Darwin thinks atolls grow smaller.
Murray's theory not improbable.

Rate of growth of reefs.

Can be determined by observation.
Agassiz's estimate 1″ in 8 years, or 1′ in a century.
Others estimate 2′ in a century.
Coral 698′ deep is 548′ below growing depth.

*Nature, Dec. 9, 1897, LVII, 137; Mar. 24, 1898, LVII, 494-5; July 7, 1898, LVIII, 221.

In opposition to the theory of subsidence, see A. Agassiz in Am. Jour. Sci. Feb. 1898, V, 113-123, and same for Aug. 1898, VI, 165-167.



At 2′ in a century it would require 274 centuries to attain this thickness.

Change by crystallization from original form.

All fossil reefs must have grown under more or less similar conditions of depth and temperature.

Reefs at the Falls of the Ohio.

Possibility of other conditions.

Temperatures are constantly lowering.

Life began in warm seas and climates.

The tendency is to adapt to colder conditions, rather than to originate in cold climates and to change from colder to warmer.

Coral reefs teach that,

I. Coral limestone is made by animal growths, assisted by wave work and consolidation.

II. Coral limestones are of marine, shallow water origin.

III. They attain great thickness by subsidence

IV. Our limestones contain near-shore life, and are therefore of near shore and shallow water, rather than of deep-sea origin.

II. *Microscopic marine animals.*

Foraminifera have (mostly) calcareous skeletons.

Live near surface of seas.

Dying, their skeletons sink to bottom, forming "*ooze.*"

Chalk made up of such calcareous skeletons.

Skeletons found to depths of 13,800′.*

Below that depth these skeletons are dissolved by pressure and carbon dioxide in the water.

III. *Molluscan and other calcareous shells and skeletons.*

(Worms, echini, crabs, crinoids, etc.)

Examples: coquina of Florida.

Encrinital limestone.

B. SILICEOUS DEPOSITS FORMED BY ANIMALS.†

Spicules of sponges accumulate.

Form cherts, flints, or hornstones.

* On Foraminifera see Zittel's text-book of Paleontology, Eastman's translation, vol. I, part I, 18–37. London and New York, 1896. Has bibliography. The Atlantic. By C. Wyville Thomson, 1, 199–203; 249. New York, 1878.

† Zittel's Paleontology, Eastman's translation. I, part I, 42+. Colloid silica. Jukes-Brown and Hill. Quar. Jour. Geol. Soc., Aug., 1889. XLV, 403.

On fossil sponges of the flint nodules in the Lower Cretaceous of Texas. By J. A. Merrill. Bul. Mus. Comp. Zoo. July, 1895. XXVII. 1–26.

Review Amer. Geol., Jan. 1896, XVII, 52–53.

Keyes in Amer. Jour. Sci., Dec., 1892. CXLIV, 451.

Hovey, Amer. Jour. Sci., Nov., 1894. CXLVIII, 401.

Lawson, 15th U. S. Geol. Surv., 420, 1895.

Extensive deposits of chert in Missouri, Tennessee, Arkansas, England, etc.
Possibility of chert being derived from the skeleton of diatoms.

C. PHOSPHATIC DEPOSITS FORMED BY ANIMALS.

Droppings and bones of marine animals or birds.
Accumulate in sea bottom or on arid land.
Guano on the islands of Peru in an arid region.
No rain to wash it away.*
Phosphate rocks of Tennessee and Arkansas.
Sometimes concentrated, as in the rivers of South Carolina.

We have now gone over all the *different methods by which rocks are made.*

All rocks fall under one of these heads and are made in one of these ways.

All rocks have originated either as
- Mechanical sediments, deposited in water, or by wind.
- Chemical deposits, deposited from solution.
- Igneous, from fusion.
- Organic, made by plants or animals.

All these deposits are subject to metamorphisms and change of position of bedding. (See Structural Geology, part IV.)

MAN AS A GEOLOGIC AGENT.†

Man's work is confined to modifying the operations of nature.
Of comparatively little importance because the element of time is wanting for his works.

I. Man's influence on plants.
II. " " " forests.
III. " " " animals.
IV. " " " land changes.

I. MAN'S INFLUENCE ON PLANTS.

Domesticated and cultivated plants formerly all wild.
Distributed over the world by man intentionally.
Examples: Wheat, oats, rye, beans, corn
Potatoes only since the discovery of America.
Cocoanuts, bananas, date palms, rice, sugar cane, cotton, coffee, oranges, in warm climates only.

* Note on Clipperton atoll. By W. J. Wharton, Quar. Jour. Geol. Soc., LIV. 228–9. London, 1898.

†The earth as modified by human action. By G. P. Marsh, New York, 1885.

Ornamental plants imported and scattered by dealers.
Forest trees.
Examples: eucalyptus and palms.
Other plants accidentally distributed:
Tumble weed, Russian thistle.
Weeds along roads and railroads.*
Cockle in wheat.

II. MAN'S INFLUENCE ON THE FORESTS.

1. *By planting:*

Eucalyptus, introduced from Australia; Lombardy poplars from Europe.
In Switzerland, forests planted to prevent avalanches.
On the west coast of France, for resin and to stop the shifting of sand dunes.
Willows planted on canals and streams to prevent cutting.
To prevent landslides.

2. *By cutting away.*

Destruction of forests for lumber, charcoal, tanbark.
Destruction by forest fires; by grazing.

A. Effects of forests on the scour of streams.
Cutting of bamboos along streams permits scour.
Cutting mangrove swamps permits scour of the coast: no filling.

B. Effects of forests on floods by:
Holding back water in leaves and debris.
Holding back snow from melting rapidly.

C. Removal of forests exposes the soil to sun and drouth, and it cracks and lets in decomposing agents.

Questions to be considered:
Do forests change climate?
What is climate?
Annual variations.
Long series of observations necessary to determine the climate.

III. MAN'S INFLUENCE ON ANIMAL LIFE.

Some animals cared for and domesticated.
Others decimated or exterminated.

*The water hyacinth. Bul. 18, U. S. Dept. Agriculture, Division of Botany. Washington, 1897. Tumbling mustard. Circular No. 7. U. S. Department of Agriculture, Division of Botany. Washington, 1896.

I. *Animals preserved and distributed voluntarily.*

Horses, sheep, camels, cows, pigs, chickens, geese, bees.
Preservation of game.
Oysters planted in brackish water.
Fishes hatched and distributed over the country.
Slavery.
Africans carried to America.
Mingling of European, American, African, and Asiatic races.
Mingling of races in Brazil through the slavery of Africans and aborigines.

II. *Animals distributed involuntarily.*

a. Injurious or parasitic insects.

Colorado potato beetle.
Hessian fly.
Scale insects imported on fruit.
Of 73 injurious insects of primary importance in the United States, 37 are introduced, all but one accidentally.*
Gypsy moth introduced in 1869 in Massachusetts; has cost a million dollars, and will cost 1½ millions more to get rid of it.

b. Harmless animals developing into pests.

English sparrows in United States since 1850–67.
Parrots of Australia.
Rabbits.

Marine life likely to be modified by the Suez Canal and the Panama Canal

III. *Animals exterminated, or nearly so.*

a. Dangerous or injurious: squirrels, snakes, panthers.
b. Game valuable for food, fur, or hides.
Bears, beavers, buffaloes, whales, fur seals.
c. Wanton destruction.
Birds of the guano islands.
Buffaloes.

IV. MAN'S INFLUENCE ON THE LAND.

Reclaiming land.

Marshes and swamps drained (elevated marshes).
Sea marshes: Holland.

*Spread of land species by the agency of man. By L. O. Howard, Science, Sept 10, 1897. New series, VI. 382–388.

Lowering Swiss lake for land.
Raising river banks.
Levees of the Po bring it above the farms.
Levees of the Mississippi.

Protection of land.

From the sea by dykes and sea walls.
Example: Holland, extensive works.
From streams, by paving and straightening channels.

Modification of land.

By building dams and reservoirs that silt up.
By cutting bars, dredging basins.
By cutting timber from sandy lands and thus starting dunes.
By planting on dunes and stopping them.
By irrigation: Egypt, Spain, California.

Placer mining.

Method of work and amount of earth washed down.
Fills streams and overflows valleys.

*Cultivation of the soil.**

Cultivation greatly increases chemical activity in soil.

I. Erosion hastened; ground not protected by plants.
II. Erosion is checked where the land is terraced, as in Switzerland.

Checking stream erosion.

Mattrasses and piles at Pine Bluff, Arkansas.
Levees of the Mississippi River, confining it to channel.
Straightening and paving the Rhone and other swift streams in Switzerland.
Using the falls for power, and thus checking the cutting.
Example: Niagara Falls.

Future water storage.

Will prevent or check floods, and retard erosion.

Geological deposits made by man.

Refuse heaps about cities and towns.
Those of large cities dumped into the sea from scows and ships.

Cities buried.

By dust storms of Africa.
Sand dunes of Bermuda.
Volcanic dust of Vesuvius.
Example: Herculaneum and Pompeii.

Ocean deposits are receiving the rejectamenta of civilization and preserving them as fossils.
Distribution over the entire globe by means of navigation.

* The economic aspects of soil erosion. By N. S Shaler. National Geographic Mag. Nov., 1896. VII, 368-377.

PART II.

STRUCTURAL GEOLOGY, OR THE MODIFICATION OF ROCKS.

Structural Geology treats of the kinds and arrangements of rocks and the changes to which they are subject.

Rocks are any materials forming the earth's crust.

They are (1) *sedimentary or stratified* and (2) *igneous or unstratified.*

SEDIMENTARY OR STRATIFIED ROCKS.

Sedimentary rocks cover nine tenths of the land and all of the sea bottom.

They average several miles in thickness with a maximum thickness of twenty miles.

Sedimentary rocks may be hard or soft; there is no line of demarkation between the consolidated and the unconsolidated.

There is no sharp line of demarkation between the materials of these rocks.

They all intergrade.

			UNCONSOLIDATED.	CONSOLIDATED.
Stratified rocks.	Shallow water deposits.	Arenaceous, or sandy.	Shingle	Breccia.*
			Gravel	Conglomerate, puddingstone.
			Sand	Sandstone or quartzite.
		Argillaceous, or clayey.	Clay	Shale or slate.
		Calcareous, or limy.	Ooze	Chalk, limestone, marble.
		Tufaceous.	Cinders, ashes	Tuffs.
	Deep water deposits. 600′ and over.	Skeletal-Siliceous.	Ooze (silica)	Diatom shale, flint, cherts, jaspers.
	Land deposits.	Carbonaceous.	Peat	Lignite, coal.
		Arenaceous.	Sand	Æolian sandstone.
		Argillaceous.	Clay	Loess.

* 11th Ann. Rep. U. S. Geol. Surv., 319, 320, 321, Mon. XXVIII, U. S. Geol. Surv., plates VIII, XXVI.

Arthur Winslow, Lead and zinc deposits of Missouri, 464–467. Jefferson City, 1894.

Gordon, Jour. Geol. III, 307. Chicago, 1895.

BEDDING.

Stratified rocks laid down in beds, or approximately parallel layers.

Stratum (plural *strata*), beds, layers.

Lamina, a very thin layer.

Terms loosely used.

Lenticular beds are lens-shaped.

False-bedding, or plunge and flow structure.* (See plate VIII.)

Characteristics of nearly all coarse sediments.

Produced by wind-bedding of any kind.

Conformity.

Rocks conform to each other (or are conformable) when laid down in successive layers in a continuous deposition.

Unconformity indicates interruption.† (See plate VII.)

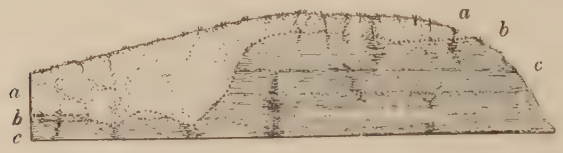


FIG. 12.—An unconformity along the line b. After the beds c were deposited denudation removed them down to b, and the beds were then spread over them.

Impressions during deposition.

Ripple-marks are found in sediments in the bottom of rather shallow water.

Made by vibration of water up to a depth of 450 feet.‡

Ripple-marks visible on the bottom of Lake Geneva, caused by the paddle wheels of steamers.

Rain-prints.

Sun cracks.

Tracks of birds and other animals.

Fossils are the hard parts or impressions of animals or plants that die in the water or are washed in from the land.

Alternation of beds is produced by the

I. Varying conditions of supply.

II. Changes of currents.

* Dutton's High plateaus of Utah, 152, 208. Washington, 1880.
Ann. Rep. Geol. Surv., Iowa, VII, plate p, 218. Des Moines, 1897.

† Ann. Rep. Geol. Surv., Iowa, V, plate I, opposite 52. Des Moines, 1896.

‡ Lapparent, Traité de Géologie, 177. Paris, 1885.
Sorby. The Geologist. II, 137–147. London, 1859.

Settling of sea-shells in mud + sand is going on all over world in quiet waters + in a few centuries when the land is eroded these fossils will be found indicating that water

Unconformity between Miocene shales below and Pleistocene beds above, exposed on the beach two and a half miles northwest of Pismo San Luis Obispo County, California. (Fairbanks, 1898.)

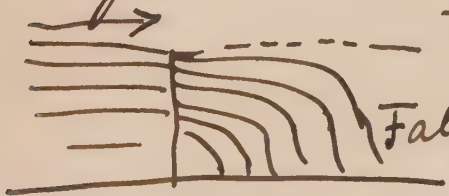
False-bedding shown on a weathered surface of oölitic limestone, Stinesville, Indiana.

It is always the disposition of rocks to spread out in layers, to fill up cracks & smooth off all areas.

Horizontal beds were at first under the sea, then were folded, tipped & exposed. Then a 2nd layer of sediments, horizontal to the first is laid down upon the top of the first which has again been submerged beneath sea.

Stratified rocks are laid down in beds or approximately parallel layers. Sentinelal beds are not perfectly even.

False bedding is formed by the in flow of streams that bring in coarse sediments.



Conformity is the way beds of rocks are put down upon each other. Beds in Plate VII are conformable with each other but the 2 different series of beds are not conformable with each

Persistence of strata.

Some strata extends for hundreds of miles.

Beds are more likely to persist parallel with the coast from which the material is derived, and in any deep sea deposits where the conditions of supply are alike.

EVIDENCES OF THE SLOW DEPOSITION OF SEDIMENTARY ROCKS.

1. Lamination of shales. Hardened clays.
2. Evidences of objects having lain long uncovered on the sea bottom.
3. Beds formed from microscopic shells which commonly accumulate slowly. Diatom beds.

The thickness of beds suggests, but does not show positively, the length of time they were forming.

HARDENING OF ROCKS.

The hardening of rocks may be produced either chemically or mechanically, or by some combination of both methods.

Chemically { 1. By the deposition of *lime carbonate*, *silica*, *iron*, or other mineral.
2. By the elevation of temperature in the presence of water.

Mechanically 3. By pressure.

Hardening is now going on; examples:

1. Bog iron and manganese deposits.
2. Hardening of road metal with iron.
3. Stone reefs of Pernambuco, Brazil, and western Palestine.
   Coquina of the coast of Florida.
   Æolian sandstone of Bermuda.
   Glacial gravels locally.
   Spring deposits cementing gravels.
4. Hardening of building stone after quarrying.
5. Experimental determination by Adams and Nicholson.*

The foregoing facts show that:

I. Stratified rocks must have accumulated by means of the same agencies, and under the same conditions, that govern the deposition of similar materials at the present time.

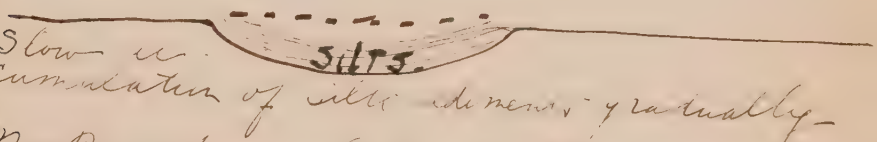
II. The oldest beds must have been laid down first and the newer ones next on top, and so on.

*Science, Jan. 21, 1898. New series VII, 82–83. Bul. Geol. Soc. Am. 1898. IX.

1. Thin beds of black shales made up of the same materials over Penn. & Ark. Shales are laden clays. When quarried they come out in thin sheets. They are laminated or laid in beds. Represent changed condition & long time.

2. Worm tubes on inside of water shell. Corals attached to a boat.

3. Skeletons of animals are so minute that many years must have elapsed to produce layers at all thick.



Slow accumulation of silt deposits gradually made a channel smaller.

Rounding of pebbles takes time.

Takes enormous time to collect any quantity of conglom.

Undertow is not strong enough to carry conglomerates far out, so they line the shore slope.

Water charged with carbon dioxide eats out lime deposits then redeposits. This hardens.

5. Fork tide cylinders under great pressure on refilling & wind out mass of coarser

III. The stratified rocks were laid down as soft sediment in an approximately horizontal position, and all changes in them, whether by consolidation, folding, faulting, or otherwise, have taken place subsequently, and are, in a sense, accidental.

UNSTRATIFIED OR ERUPTIVE ROCKS.

DISTINCTIONS BETWEEN SEDIMENTARY AND IGNEOUS ROCKS.

Sedimentary or stratified rocks.	*Igneous or unstratified rocks.*
Clastic, or of fragments	Crystalline from fused state.
Bedded	Massive; different flows may have bedded appearance.
Contain fossils	No fossils except in inclusions and in tuffs.
No flow structure	Flow structure.
No gas cavities	Gas cavities.
Texture varies according to currents in which deposited.	Texture varies according to conditions of cooling. Under pressure are coarsely crystalline. Without pressure are more glassy.

IGNEOUS ROCKS MAY BE GROUPED

With reference to conditions of cooling, as:

- Plutonic. — Those cooling under pressure at great depths. They are, or have been, deep-seated, and have been exposed here and there by erosion.
- Volcanic.

With reference to composition, as:

- Acid, containing 60–75% of silica. They are light-colored. Fuse with difficulty. Stiffen readily and form glasses.
  - Granites.
  - Gneisses.
- Basic, containing less than 60% of silica, and high percentages of fluxes, lime, soda, potash, iron, etc. They are dark colored.
  1. Easily fusible (basalts).
  2. Medium fusibility (andesites).
  3. Difficult to fuse (trachites).

Hardening of Rocks.

Chemically

1. By the deposition of lime Carbon
Eg – Palestine coast, – of silica & iron.
2. By the elevation of temperature near
Mechanically by Pressure. water –

1. By iron dissolves out the rocks over which the water flows. & precipitated to the bottom of ponds & bogs o Lavens –

2. Hardening of road metal with iron. Whole top of road covered with crust of iron.

3. The Sands of Palestine are reall a Calcareous Sand-stone & by the Solution at top of carbonate of lime & its deposition further down the whole is turned to lime-stone

4. Hardening of building stones after quarrying –

FORMS OF IGNEOUS DEPOSITS.

Ejected as local lava flows or fragmental material they form.

I. Lava cones; angle varies with fluidity, 3° to 25°.

II. Cinder cones; 35° to 40°.

Craters are the cup-shaped mouths of volcanoes.

Origin of the cup-shape.*

Lava sheets often spread over wide areas.

Overwhelm topography.

Deccan trap of India cover 200,000 square miles, 100′ to 6,000′ thick.

Oregon, Washington and California, 150,000 square miles.

Lava surfaces often very rough.

Origin of Table Mountains of California.

Often called trap, from the Swedish *trappa*, stairs.

FIG. 13.—Horizontal columns of basalt on the shore of the island of Fernando de Noronha.

* The moon's face. By G. K. Gilbert. Phil. Soc. of Wash., 1892. Bul. vol. XII, 241-292. Lassen Peak folio of U. S. Geol. Surv. By J. S. Diller. Washington, 1895.

Form of Igneous deposits
Lava Sheets.

Mts. in Arizona.

Flat-top of Mts. in Arizona due to lava.

Columns may be horizontal and in piles.
Examples: Fingal's Cave, Scotland.
Giant's Causeway, Ireland.
They may curve.* (See plate IX.)

Intrusions.

Between beds.
Vertical.
Horizontal
Laccolites (see page 132).
Across beds.
Dikes.
Irregularities of dikes (see page 132).

Tuffs.

Fragmentary material; take the slope of loose sands or cinders.
Deposited in water; may have fossils.
Gross forms of tuffs like those of sedimentary rocks, but limited in extent to the vicinity of the volcanoes. (See plate X.)

STRUCTURAL FEATURES COMMON IN ROCKS.

JOINTS IN ROCKS.†

Clean-cut faces, disregarding bedding.
All rocks have more or less of them.
Common in shales; "block coal" of Indiana.
Seen and used in quarries.
Pass through pebbles.
May lie in two or more directions.
Sandstone dikes formed in the cracks.‡
Often influence topography.§
Cliffs of Cayuga lake; in loess.‖

Basaltic columns.
Often lavas of horizontal sheets are vertically jointed with hexagonal columns.¶

* Iddings. Am. Jour. Sci. 1886, vol. 131, 321–324.

† Daubrée Géologie experimentale, 300–318 Paris, 1879.
On the fracture system of joints. By J. B. Woodworth. Proc. Boston Soc. Nat. Hist. 1896. XXVII, 163–183.
Crosby, Proc. Boston Soc. Nat. Hist. XXII, 72–85. Boston, 1884; XXIII, 243–248. Boston, 1888.

‡ Sandstone dikes. By J. S. Diller. Bul Geol. Soc. Amer. 1889, I, 411–442. Intrusive sandstone dikes in granite. By W. Cross, Bul. Geol. Soc. Amer. 1894. V, 225–230. Dikes of Oligocene sandstone....in Russia. By A. P. Pavlow. Geol. Mag. Feb. 1896, III, 49–53.

§ Dutton's High plateaus of Utah, 280. Washington, 1880.

‖ Ann. Rep. Geol. Surv. Iowa, VII, 235 Des Moines, 1897.

¶ J. Lomas, Proc. Liverpool Geol. Soc. VII, pt. 3, 323–5. 1895. Open-air studies. By G A. J. Cole, plates VI and VIII, op. pp. 172 and 183. London, 1895.

Basaltic columns, some of them curved; popularly known as "the Devil's post-pile." Exposed on the middle fork of the San Joaquin river, Yosemite National Park, California.

Stratified tuffs east of Red Rock, Kern county, California. (Fairbanks.)

Joints refers to certain fractures in rocks.

Theories of causes of joints.

I. *Contraction*, as sun-cracks in mud.
These are not straight and clean cut.

II. *Torsion*
Daubrée's experiments with ice.*

III. *Earthquakes.*
Effect of sharp snaps on rocks under strain.

THE CLEAVAGE OF ROCKS.†

Cleavage is the easy splitting of rocks in parallel planes.
Kinds of cleavage peculiar to rocks.

I. *Crystalline* cleavage. Examples: gypsum, mica.
Confined to crystalline forms.

2. *Bedding* is due to water sorting; and follows bedding planes; sometimes called flagstone cleavage.

3. *Slaty cleavage.*

General facts regarding slaty cleavage.

1. It is always associated with folded and contorted beds.
2. It cuts across the bedding planes at various angles.
3. It occurs only in fine grained rocks.
4. The included particles are parallel to the cleavage planes.

Experiments show that:

I. Iron cooling without pressure is *granular;*
when drawn like wire it is *fibrous;*
when rolled it has cleavage structure or is *scaly;*
that is, the granules are flattened.

II. Parallel re-arrangement of mica scales in clay after pressure.

III. Pressure on beeswax causes it to separate into folia, or scales.

These facts all suggest that *slaty cleavage is caused by pressure at right angles to the cleavage planes.*

This is borne out,

1. By finding wrinkled sand beds in slates.
2. By the general folding of the rocks.
3. By the deformation of fossil shells in slates.
4. By minerals in the slates being all parallel to the cleavage.

SCHISTOSITY.

Schistosity is a parallel splitting of the rock in thin layers, but, unlike slaty cleavage, the layers are more or less wrinkled.

* Géologie experimentale. Par A. Daubrée. 300-314. Paris, 1879.

† On cleavage, joints and folds, see Dale in 16th Ann. Rep. U. S. Geol. Surv. Pt. I, 549-570. Cleavage and fissility. C. R. Van Hise, 16th Ann. Rep: U. S. Geol. Surv. Pt I, 633 (bibliography). Washington, 1896.

Deformation of rocks. By C. R. Van Hise. Jour. Geol. 1895. IV, 449-483; 593-629.

The rocks often have a felted appearance.
Schistosity is supposed to be due to squeezing or shearing.*

CONCRETIONS.†

Concretions commonly occur as round or lenticular masses of various sizes from that of a pin-head to several feet in diameter.
How they differ from pebbles and boulders.
Due to the tendency of certain minerals in solution to segregate as they are deposited.
May occur in either igneous or sedimentary rocks.
I. Contemporaneous with enclosing beds or part of them. Rogenstein, bauxite, garnets.
II. Formed subsequently.
Bedding planes sometimes pass through concretions
Commonly arranged along bedding planes.
Concretions in sandstone are apt to be of lime; those in limestone are apt to be of silica.
Liable to form about bones or shells.
Loess-puppets of lime in the loess.
Fantastic forms.

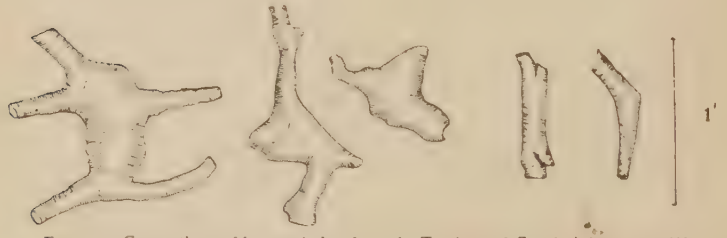


FIG. 14.—Concretions of iron and clay from the Tertiary of South Arkansas. (Harris.)

Geodes or hollow concretions.
Geode beds of Warsaw, Ill.; Keokuk, Iowa; Indiana, etc.
Geodes may be empty or filled with calcite, dolomite, gypsum, chalcedony, quartz, zinc blende, pitch, petroleum.
Formed after the deposition of the beds.
The "iron pots," or iron geodes, of Arkansas.

* Hoskins, 16th Ann. Rep. U. S. Geol. Surv., part 1, 870. Washington, 1896.
† Merrill, Proc. U. S. Nat. Mus. XVII, 87–8 and plate. Washington, 1895.
John Ruskin, Geological Magazine, 1867, 338, 481; 1868, 12, 156, 208; 1869, 529.

Concretions.

Resemble water-worn pebbles. They are formed from the inside. Oölite - concretions of one kind. Some are made when the rocks were made & some since.

Mineral water of some springs when cooling deposits concretions that are constantly growing.

The hardening of these concretions pervades thro' several bedding planes of rocks. Layers - pockets; they occur in the glacial silt.

Geodes - Hollow concretions. Some lined with quartz. Made in rocks after [illegible]

*Oölites** and *pisolites* (pea stones) are concretions of smaller size.

Formation of pisolite at Carlsbad; called *rogenstein.*

Siliceous oölite from Pennsylvania.

Oölitic limestones of Indiana.

Concretionary structure in crystalline rocks.

Due to concentric arrangement of the crystals in cooling.

"*Orbicular* granite."†

Note that

I. *Concentric staining* is not properly a concretion. It is caused by penetration of mineral-charged waters and the oxydation or deposition of the minerals.

II. That *exfoliation* produces rounded forms which are not concretions, though resembling them.

CONE-IN-CONE.‡

DISPLACEMENTS OF ROCKS.

EVIDENCES OF ELEVATION AND DEPRESSION. (See plate XI.)

I. Evidences that most sedimentary beds were deposited in the ocean.

1. They are water-bedded.
2. They contain remains of marine animals.

II. As they are now on land, in hills and mountains, they must have been elevated.§

But it has been shown that while the earth's surface rises in one place it is depressed at another, so that there must be a warping of the beds.

This may produce *tilting, folding, or faulting.*

Theory of isostacy.

Isostacy refers to a state of equilibrium.

(This is discussed at length under Physiography, page 274.)

* Bibliography of oölites, T. C. Hopkins, 21st Ann. Rep. Indiana Geol. Surv., 409-410. Indianapolis, 1897.

The Geologist, 1858. 72-73. (Insect eggs as oölites.)

Nature, Nov. 12, 1896, LV, 40. (Bacterial origin of oölite.)

E. B. Wethered, Quar. Jour. Geol. Soc., 1891. LI, 196. (Organic origin.)

E. H. Barbour and Jos. Torrey, Am. Jour. Sci., 1890, CXL, 246-9.

G. R. Wieland, Am. Jour. Sci., 1897. CLIV. 262-4. (Pennsylvania siliceous oölites.)

Rothpletz, Amer. Geol. 1892. X, 278-282.

Griswold and Agassiz, Bul. Mus. Comp. Zool., vol. 38, No. 2, 29-62. (Florida oölites.) Jour. Geol. V. 312-13.

† Bulletin de la Commission Géologique de Finland, No. 4, plates 1 and 2.

Concretions in Canadian rocks. By T. C. Weston. Trans. Nova Scot. Sci. 1894-5, IX, 1.

Geikie's Ancient volcanoes of Great Britain, I, 22. Illustration. London, 1897.

‡ Am. Jour. Sci., 1885, 130, 78-79. Geol. Mag., Nov., 1892. IX, 505-7.

H. C. Sorby, Transactions Brit. Assoc. 1859. 124.

20th Ann. Ann. Rep Ind. Geol. Surv., 82. Indianapolis, 1896.

21st idem, 305-308, Bibliography. Indianapolis, 1897.

Gresley, Quar. Jour. Geol Soc. 1894. L, 731-739, 2 plates.

Abstract Amer. Geol. 1894. XIV, 399-400.

A. J. Sachs, Proc. Austr. Assoc. Adv. Sci. 1893, IV, 327-8.

§ Fairbanks, Amer. Geol., Oct., 1897. XX, 245,213.

Fossil stumps of a Carboniferous forest exposed in a quarry at Patrick, Glasgow, Scotland. (1898.

I Concentric staining is not a concretion.

displacement of Rocks.

This is one of most important facts we have to do with in Geology.

Evidences of elevation & depression.

Fossils do not crawl up on rocks.

The broader structural features of the earth are *exhibited in folds and faults.*

Means of studying rock-beds.

I. Artificial sections in mines, shafts, and wells.
These seldom penetrate more than 3,000′.
Well near Leipzig 6,560′.

II. Natural sections exposed in cañons:
Grand Cañon is over 6,000′ deep

III. Natural sections exposed in eroded folds and faults.
These bring the deep-seated beds to view.

Tilting.

Recent tilting shown in the Great Lakes region by level lines.
Tilt to the southwest.
If tilting should continue at this rate Chicago, in 500–600 years, will have occasional discharge to the Illinois river; in 1,500 years it will be continuous. At the present rate, in 3,000 years Niagara will cease to flow and the water of the Great Lakes will discharge toward the south.*

Folding.†

One of the postulates of geology is that:

I. *Sedimentary rocks were originally laid down in approximately horizontal beds.*

If this is true, it follows that:

II. *Folds, tiltings and faults in sedimentary rocks were made subsequently.*

Folds are wrinkles of various sizes.

I. May be broad and gentle, with axes far apart. (No. 4 in fig. 16.)

II. May be sharply crumpled.

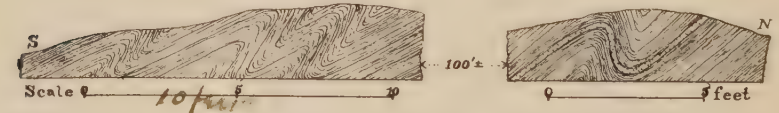


FIG. 15.—To illustrate folded structure. Sketched from exposures along a railway cut, five miles southeast of Bengal, Indian Territory. (Drake.)

Crumpling is very marked in many schists.

III. May be overturned. (Nos. 6 and 11 in figs. 16 and 17.)

IV. May be radiate or fan-shaped, as in the Alps.

*G. K. Gilbert, Nat. Geogr. Mag. Sept. 1897, VIII, 747.

†The mechanics of Appalachian structure. By Bailey Willis. 13th Ann. Rep. U. S. Geol. Surv. Pt. II, 211–282. Washington, 1893.

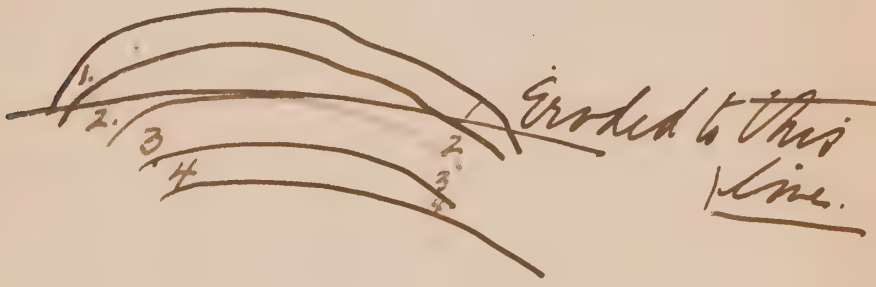
The folds of the mountains. Open-air studies. By G. A. J. Cole, 283–313. London, 1895.

Deformation of rocks. By C. R. Van Hise. Jour. Geol. 1896, IV, 312–353.

Unconformity represents a land surface & a long extent of time. 195.

I & II see syllabus.

III Natural sections exposed in eroded folds & faults; these bring the beds to view.



Technical names applied to parts of folds.

Outcrop, an exposure of rock in place at the surface.

Axes, planes along which folds occur.

Dying out and overlapping of axes.

Anticline.

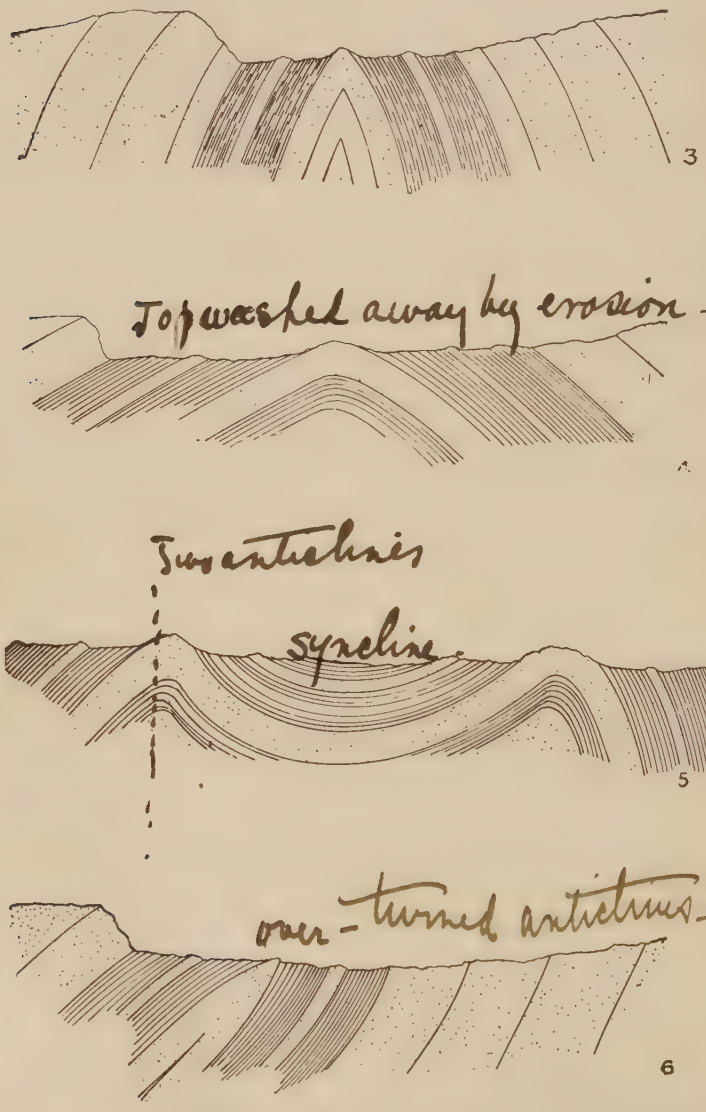


FIG. 16.—Sections showing types of structure and topography in the Paleozoic region of Southwest Arkansas. No. 5 is a section across two anticlines and one syncline. (Ashley.)

Outcrop = an exposure of the rock at the surface.

Axes = planes along which the folds occur.

Anticline = when a bed rises vertically or in the opposite direction from each other.

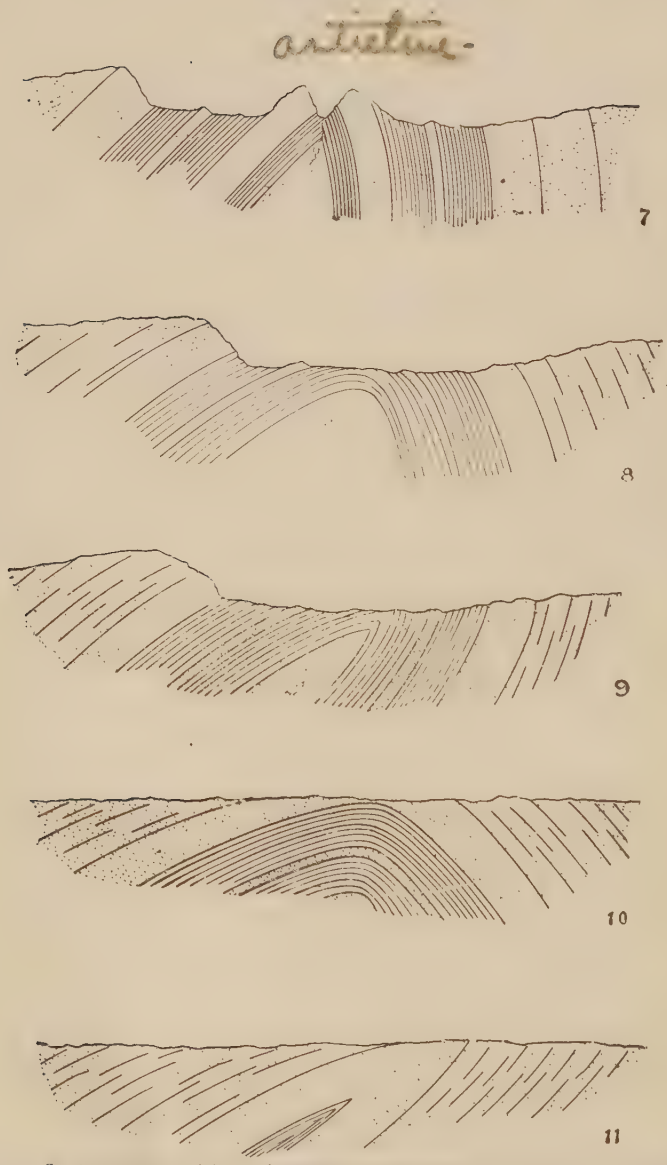


FIG. 17.—Sections across anticlines showing types of structures and topography in the Paleozoic region of Southwest Arkansas. The dotted areas represent sandstones, the shaded parts shales. (Ashley.)

Syncline (middle of No. 5 in fig. 16).
Monocline, or a slope in one direction (but not an overturn).
Location of axes by the use of the dips, when the exposures are many or few.
Dip is the slope of a bed of rock, down which water or a ball would run.
Clinometer and compass.
Caution against *false-bedding*.
Caution against apparently horizontal beds.
Caution against "creep."*
Use of dip in locating beds in depth.
Width of outcrop varies with dip.
Use of dip in determining thickness of rocks.

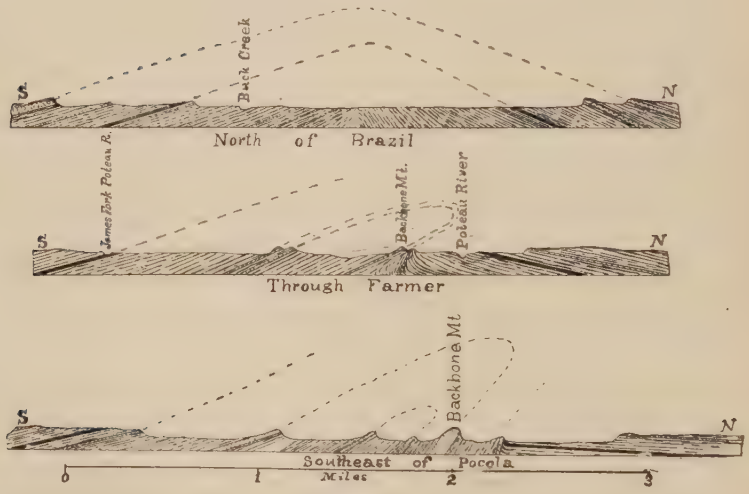


FIG. 18.—North-south sections, ten miles apart, across an anticline in the Coal Measures of Indian Territory. The section at the top is farthest west; toward the east the fold merges into a fault. (Drake.)

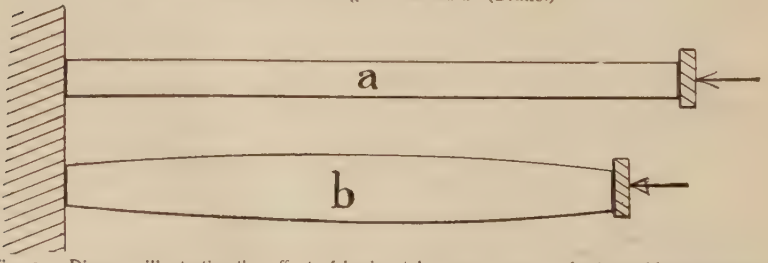
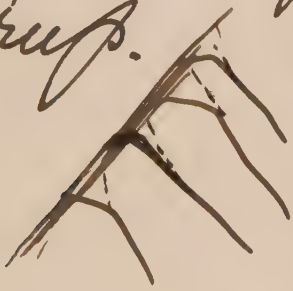


Fig. 19.—Diagram illustrating the effect of horizontal pressure upon a horizontal homogeneous bed. (Ashley.)

*For illustration of "creep," see Scott's Geology, page 82.

Synclines = trough where
2 anticlines meet.

Monocline = where beds all
dip in one direction /
Dip = slope of a bed of rock
The < a rock makes with
horizon.
In taking dip of rocks you
have to be cautious about
false bedding.



Creep. As these beds
freeze & thaw
they tend
to glide down
hill & this is
Creep.

Strike of rocks.
Direction on the surface.
The water line against the face of a bed.
Use of strike in tracing a bed on the surface.

Dying out of folds.
In length; overlapping of folds.
In depth, as shown in mines, where the rocks crush or compress in depth instead of folding (see page 200).

What is meant by rocks being *geologically higher*.
Not a matter of hypsometry.

How outcrops with various dips look on geological maps.
Meaning of colors on geological maps.
Appearance of syncline.
Of anticline.
How outcrops in folded areas follow the hills according to dip.

*Overturns.**

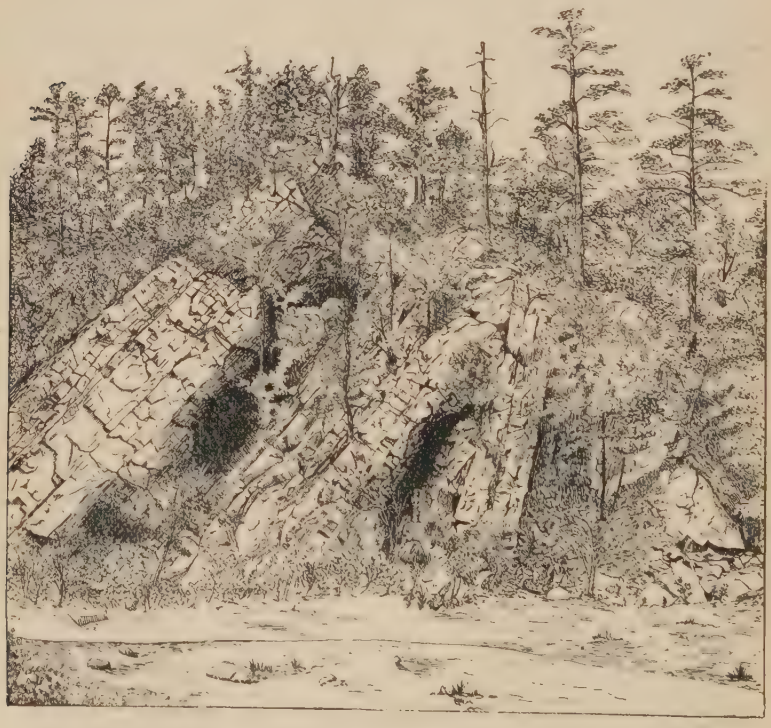
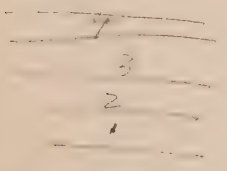
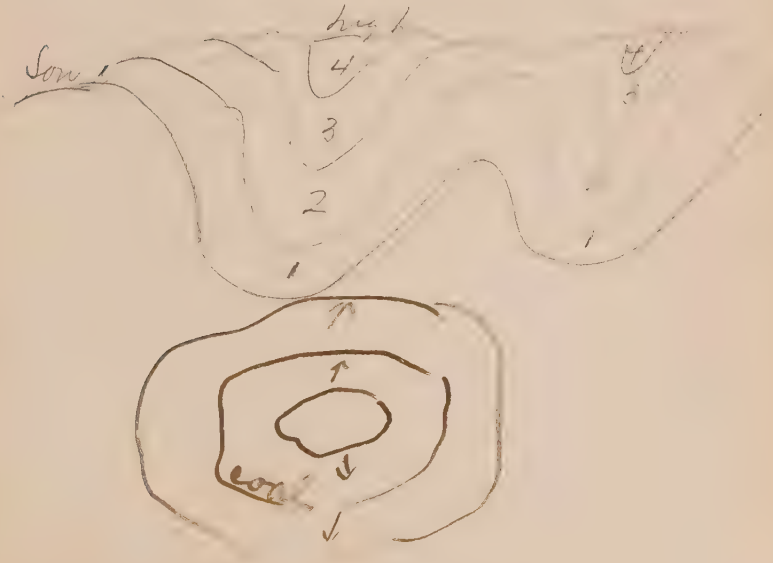


FIG. 20.—An overturned anticline. The resisting beds are sandstones. (Ashley.)

*16th Ann. Rep. U. S. Geol. Surv. Part I, 550. Washington, 1896.


4
3
2
1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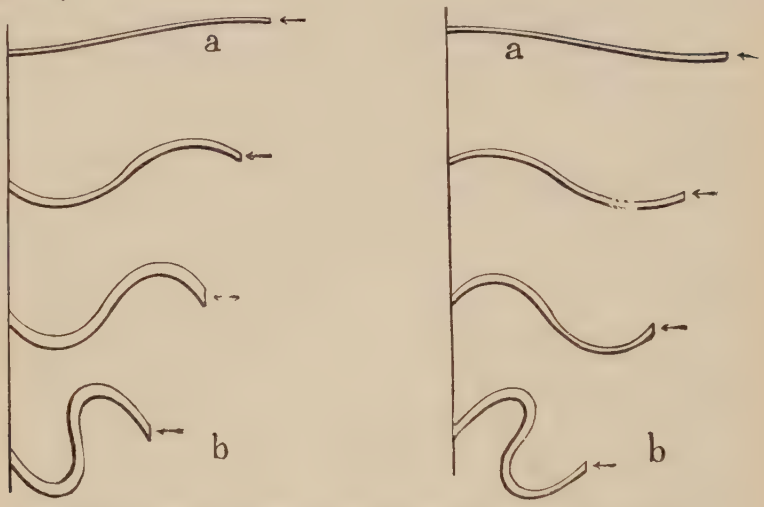


FIG. 21.—Diagrams showing the effect of original dip upon ultimate structure. (Ashley.)

Influence of original dip upon overturns.

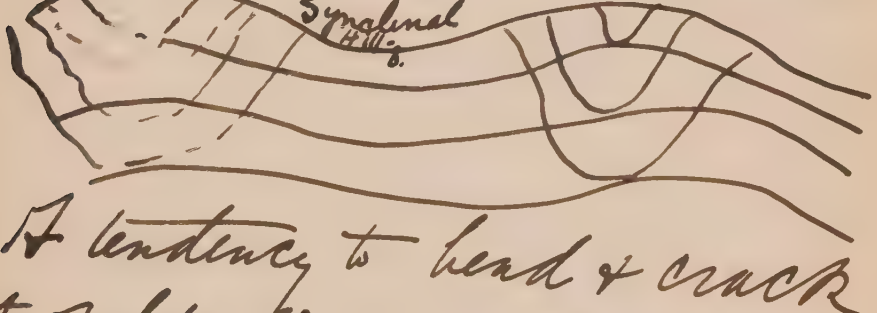
Effects of folds on topography.

1. Anticlinal valleys.
2. Synclinal valleys.
3. Synclinal hills.
4. Monoclinal hills.
5. Anticlinal hills.

FIG. 22.—Profiles of an anticlinal ridge, Antoine mountain, Pike county, Arkansas. (Ashley).

Initial dip - the dip of rocks when pressure is first brot to bear on them.

Streams will avoid hard rock of ridges & will seek out soft layers -



A tendency to bend & crack the folds in (a) on the summit of anticlinis & to compress the folds at (b.) This results in valleys cut under (a).

B = synclinal hill. a = anticlinal valley.

Isoclinal.

FAULTS.*

Faults are displacements along lines of fracture.

They may run in any direction.

They can only take place after the formation of the beds so faulted.

They occur singly or in sets.

These sets may cross each other at various angles.

Faults are called normal or reversed, according to the nature of the displacement.

I. NORMAL, OR GRAVITY, FAULTS.

Produced by *tension of the beds*, allowing one side to settle.

"Faults have to the downthrow," a rule originating in a region of normal or gravity faults.

Meaning of the expression.

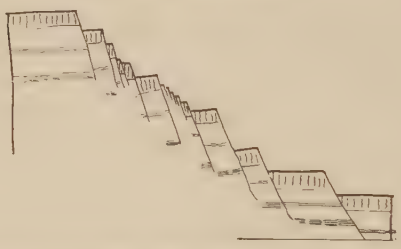


Fig. 23.—Section through normal faults showing the repetition of the same bed.

FIG. 24.—Section through normal faults.

Gravity faults occur in *regions of surface contraction*.

Contraction may be due to:

1. Drying of sedimentary rocks.
2. Cooling of hot rocks.

Oregon lakes;† Dead Sea and the Jordan.‡

California valleys, but widened by erosion.

Deceptive thickness.

*Fault-rules. By F. T. Freeland. Trans. Am. Inst. Mining Engs, XXI, 491–502. N. Y., 1892-3. Contains short bibliography.

La face de la terre. Par E. Suess Tome I, 138–184. Paris, 1897.

Heim and De Margerie, Dislocations. Zurich, 1888. (Bibliography.)

Slickensides and normal faults. By T. Mellard Reade. Proc. Liverpool Geol. Soc, 1889. VI, 92–114.

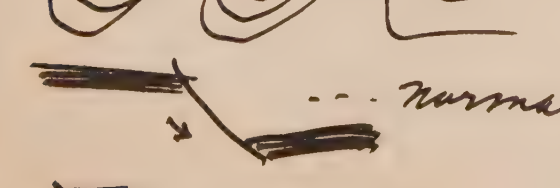
†Topographic features due to landslides. By I. C. Russell, Pop. Sci. Monthly, Aug. 1898. LIII, 480–489.

Lakes of North America. By I. C. Russell, 29–31, Boston, 1895.

‡See maps in the survey of Western Palestine. By E. Hull, London, 1886

Faults are displacements of rocks in their original relations to each other. As long as beds are continuous there is no fault. A normal fault is produced by the tension of the bed allowing one bed to slide over the other.

A reversed fault is where 2 surfaces are pressed together + the bed is pushed up.



Folds so long as they do not shift.

... normal, gravity, tension fault.

Fig. 25.—Reversed fault displacing a quartz vein. Coyote mine, San Diego County, California.

II. REVERSED, OR THRUST, FAULTS.

Caused by pressure.
Rule regarding *hade* reversed.
Importance of this in mining, to locate veins and beds.

Folds often merge into faults.

Amount of displacement in faults.
Fraction of an inch.
Faulted pebbles.
15,000′ in Sierras.
20,000′ in Appalachians.
40,000′ in Wasatch Mountains, Utah.
Overthrust faults of Scotland.

Continuity of displacements.
Faults die out below.
Die out longitudinally.
Some short; one in Africa 120 miles long.*
Another 270 miles long.

*Nature, April 22, 1897, LV, 581.

Amt. of displacement
produced by Faults.
Enormous vol of 40000.
to Minute Faults

Shear fautls have varying downthrow.

Direction of displacement is not necessarily vertical, but may be *lateral*, or side thrusts; or it may be *twisted*, one side moving one way, the other the other, forming a double shear fault.

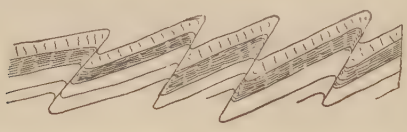


FIG 26.—Reversed faults dipping in the same direction

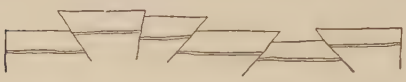


FIG. 27.—Section showing displacements by reversed faults dipping in different directions.

Ages of faults.

Faults must be newer than the rocks affected.

If Cambrian and Carboniferous rocks are faulted, the faults must be post-Carboniferous.

Faults in Nova Scotia since the glacial epoch.*

Edges of faults not straight, but ragged and more or less crooked.

Slickensides are striæ or scratches on rocks, between faces that have slipped over each other.

Resemble glacial striæ.

DETECTION OF FAULTS ON THE SURFACE.

I. By the abrupt termination of beds along a strike.
   Examples: map of France; Pennsylvania county maps.
II. By newer rocks apparently dipping beneath older ones.
   Rush creek fault.
III. By mineralization on fault line.
IV. By certain springs emerging on the fault line. (See No. II.)
V. By changes of topography.
VI. By change of rock or soil on the strike of the fault.

ECONOMIC IMPORTANCE OF FAULTS.

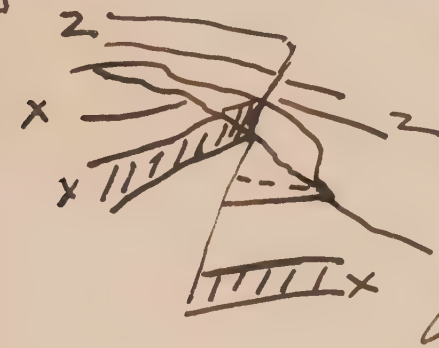
Mineral veins form in them.

Mineral deposits displaced by them.

*G. F. Matthew, Bul. XIII, Nat. Hist. Soc. of New Brunswick, Nov. 1894, 34-42.

Shear faults = The name given to the end of a fault where it dies out

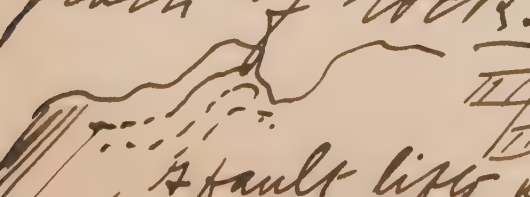
= double shear fault =



Beds first laid down + displaced. Then the surface is eroded + the beds z laid down. Then another slight fault.

Slickensides are striæ or scratches on rocks between faces that have slipped over each other. Many in coast ranges.

Wherever we find misfits in grain of rock — argues fault.



THE ALTERATION OF ROCKS.

Rocks do not remain the same, but are subject to changes. Metamorphism is one of these changes.

METAMORPHISM.*

The change, whether chemical, mineralogical, or other rearrangement, that rocks undergo after their original formation or deposition.

It often obscures the

I. Original form.
II. Method of formation.

Not all changes are metamorphism.

Changes other than metamorphism.
- Decay. Example: formation of kaolin.
- Coloration: mottling of rocks.
- Hydration. (See page 220.)
- Sandstone changes to quartzite at the surface only.
- Limestone and fossils change to crystalline marble.
- Lignite changes to coal.
- Coal changes to anthracite and graphite.

Changes may be:

I. In form and texture, but not in composition :
   - Aragonite to calcite.
   - Clastic to crystalline rocks.

II. In chemical composition by replacement :
   - Wood to silica.
   - Calcareous shells to silica.

Effects of metamorphism.

1. Bleaching.
2. Change of color.
3. Hardening and consolidation.
   - Sandstone to *quartzite.*
   - Clay and shale to *slate.*
4. Expulsion of water and vaporizable ingredients.
5. Melting, baking.
6. Crystallization, with or without change in constituent minerals, including
   - Marmarosis.

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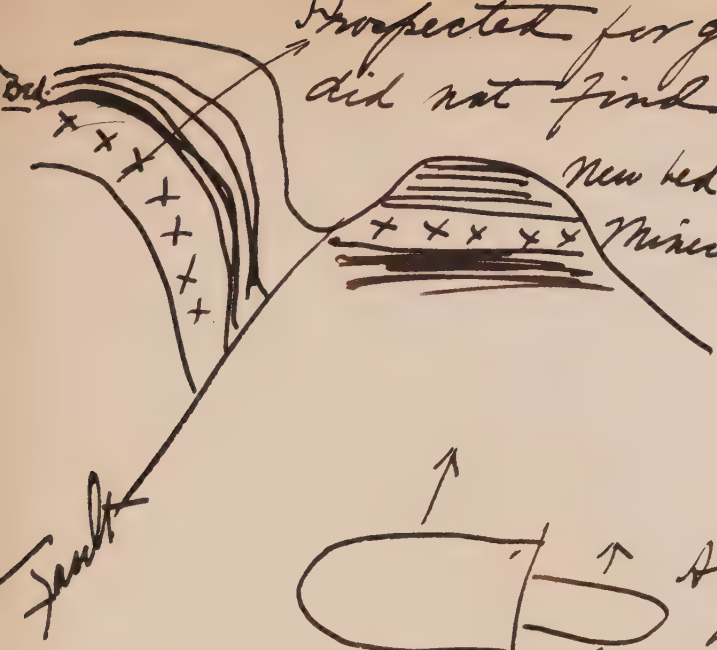
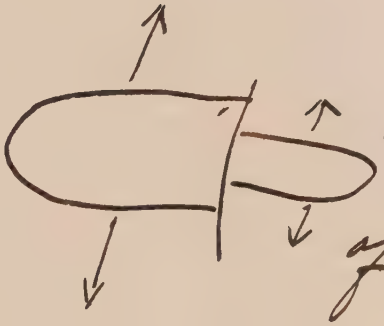
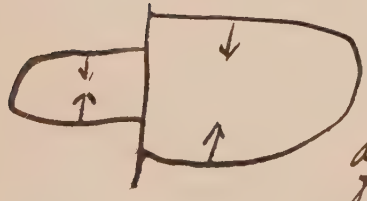
* Metamorphism of the sedimentary rocks. By C R. Van Hise. 16th Ann. Rep. U. S. Geol, Sur. Part I, 683–716. Washington, 1896.
Metamorphism of rocks and rock flowage. By C R. Van Hise Amer. Jour. Sci. July, 1898, CLVI, 75–91. Bul. Geol. Soc. Am. 1898, IX, 269–328.
Physics of metamorphism. By A. Harker. Geol. Magazine, 1889, VI., 15.
Judd, Geol. Mag. 1889. VI, 243.
The greenstone schist areas of.....Michigan. By G. H. Williams. Bul. 62. U. S. Geol. Survey. Washington, 1890.


Prospected for gold but
did not find it.
New bed.
Mineral found.
Fault


Anticline
bearing
of faulted
rocks.


Syncline bearing
of faulted rocks.

7. Production of new minerals.
8. Production of foliation and schistosity.
9. Obliteration of fossil contents.
10. Obliteration of bedding planes.

Causes of metamorphism:

1. Hot waters with CO_2 and minerals (alkalis) in solution.
2. Hot vapors and gases beneath the surface.
3. Movements in rocks, such as pressure, crushing, and shearing.
4. Intrusion of hot eruptive rocks.

Heat and moisture are the chief agents of metamorphism.

Amount of heat.

But little is necessary to produce metamorphism, for there are some minerals in metamorphosed rocks that can not stand much heat.

Amount of moisture.

But little moisture is necessary in metamorphism.
Dry heat, however, does not affect rocks far.
Certain minerals contain water.

Time an important element.

Oldest rocks usually most metamorphosed.

How heat may be produced in rocks.

1. By chemical action.
2. By crushing and shearing of rocks.
3. Intrusion of hot rocks from below.
4. Rise of interior heat. (See pages 118–120.)

Metamorphism may be { Local or contact. / General or regional.

I. LOCAL OR CONTACT METAMORPHISM.

Local metamorphism is produced by the altering effect of hot rocks on those with which they come in contact.

Igneous rocks penetrating coal in southeast Colorado have produced coke or powdery graphite.

Sometimes other beds are only reddened.

Limestone much changed near a dyke, but less away from it.

Dike in chalk in County Antrim, Ireland, has altered the chalk to the following rocks, beginning next to the dike.

1. Dark-brown crystalline limestone.
2. Saccharoidal limestone.
3. Fine grained "
4. Porcellanous "

When hot rocks come in contact with other rocks & change them it is called local or contact metamorphism.

5. Blue gray limestone.
6. Yellow white.
7. Grades into chalk.

Alteration of the slates of the Sierras by dikes.

Sedimentary beds baked to "an intensely hard and exquisitely white porcelain" by a lava sheet.*

These changes vary greatly in degree from incipient metamorphism to a change of the form and of the chemical composition of the rocks.

Experiments of Daubrée.†

II. REGIONAL OR GENERAL METAMORPHISM.‡

This name is applied to wide areas where there is apparently no connection between local igneous phenomena and the metamorphism.

Of the same nature as local metamorphism, but different in extent.

Great regions of schists come here.

Examples: New England, Wisconsin, Michigan, and Minnesota.

North of Scotland.

Interior of South America.

Regional or general metamorphism supposed to be due to the presence of metamorphosing conditions in rocks over wide areas.

Regional metamorphism is most common in regions of stress, folding, crumpling, and shearing.

It is often unequal in degree and character.

Why some beds are metamorphosed while others in the same series are not.

Due to difference:

1. In contained water.
2. In condition of or size of the particles.
3. In composition.

Metamorphosed rocks.

All schists, gneisses, some quartzites, slates, serpentines.

Why mountains often have sediments metamorphosed.

They are regions of movements, strains, slipping, etc.

Why exposed.

By erosion.

* The great rift valley. By J. W. Gregory, 137. London, 1896.

† Études synthetiques de géologie experimentale. Par A. Daubrée. 151–234. Paris, 1879.

‡ Sur l'origine des terrains crystallins primitifs. Par M. Levy. Bul. Géol. de France. XVI, 102-113. Paris, 1887.

The rocks may be heated
from below by the intrusion
by high temperatures from
below over large areas for
a long space of time —

When A is deposited
the isotherms rise
to surface just
as the were before

As you
down to th
centre of ea
the temp —
increases a
a given r
variably

They are often old rocks.
They are commonly deep-seated rocks.

GENERAL CONCLUSIONS REGARDING METAMORPHISM.

1. Metamorphism is the change of form or internal structure of either igneous or sedimentary rocks.
2. The date of the metamorphism is necessarily later than that of the making of the rocks.
3. Metamorphism is produced by:
   - I. Heat.
   - II. Pressure.
   - III. Chemical changes aided by water and alkalis.
4. Metamorphism may be local (contact) or regional (widespread.)
5. It may occur in alternate beds of a series.
6. It may effect beds either vertically or laterally.
7. Regional metamorphism is a wider extension and greater development of local metamorphism.
8. Metamorphism does not necessarily introduce new chemical elements, but may be only a rearrangement of those already present.
9. Metamorphism is seldom uniform throughout a wide area, but is often more intense here, and less so there.
10. The nature of the changes depends on:
    - I. Character of rocks affected.
    - II. Nature and intensity of metamorphosing agencies.
11. Metamorphic rocks may be either old or new.
    Metamorphism is therefore no test of the age of rocks.
12. However, all the oldest sedimentary rocks are metamorphosed, and metamorphism is generally more widespread as we go down in the geologic series.
13. Metamorphism is most common in regions of great thickness of strata because high temp. is near up from below
14. The most common forms of metamorphic rocks are: gneisses, schists, slates, some quartzites, some marbles, and some serpentines.
15. Metamorphism more frequently takes place at great depth below the surface. The metamorphic rocks now exposed have been uncovered by erosion.

REPLACEMENT.

Of woody fiber by silica. (See plate XII.)
Of shells, corals, etc., by silica. made from carbonate of lime - Sept.

A series of beds are not
all affected alike - Ex -
layers of wheat in diff. stages
subjected to heat of oven are
not affected alike - It is
largely a matter of moisture &
oil also -

PLATE XII.

Petrified logs, Chalcedony Park, near Holbrook, Arizona. Petrified logs cover more than a thousand acres at that place.

Carbonate of lime disappears
from coral, oyster shells, etc
& silica takes its place
Woody fiber by silica -
Has metamorphism been

Why do some rocks fail to be
metamorphized? Namely illus-
put in basin ordinary dough,
on top of it ~~on~~ ground wheat grains
" " this dry flour:
" " " " pulp duration of wheat
without moisture; then bake it.
By this subjection to heat these
layers are affected differently—
In just this way rocks are af-
fected by high temp. to which
they are subjected.

Metamorphism is not likely
to occur in sea except when
lava sheet has spread over.

Often shells have lain
exposed for a long time
the carbonates which were first
formed turn to silica—

PSEUDOMORPHISM.*

DEHYDRATION, or loss of water.

DOLOMITIZATION.†

Fig. 29.—Horizontal section in a quarry at Kilkenny, Ireland, showing both dolomite and unaltered limestone

Fig. 28.—Section in a quarry at Kilkenny, Ireland, showing a part of the limestone (shaded) altered to dolomite (light.) (Prestwich.)

A replacement of some of the lime carbonate of limestones by magnesia.

HYDRATION.

Anhydrite to gypsum, by taking up water.‡
Peridotite to serpentine.

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* Physical geology. By A. H. Green. 81-82. London, 1882.

†Hall and Sardensen, Bul. Geol. Soc Amer. 1894, VI. 193-198.
Klement and Högbom, Amer. Jour. Sci. May, 1895. CXLIX, 426-7.
Robert Bell, Bul. Geol. Soc. Amer. 1894. VI. 297-304.
T. C. Hopkins, Ann. Rep. Geol. Surv. Ark. for 1890. IV, 35-39. Little Rock, 1893.

‡ Magnese; its uses, ores and deposits. By R A. F. Penrose, Jr. 534-536. Little Rock, 1891.

WEATHERING.

Change of rocks on exposure.*

MINERAL VEINS.

Mineral veins are of small extent, but of great economic importance.

Minerals of economic importance, however, do not always occur in veins.

The position of mineral veins will be understood from the following table:

Economic geologic deposits

I. *Organic accumulations.*
Coal, oil, gas, peat, lignite, limestone, chalk, marble, phosphates.

II. *Bedded chemical deposits:*
Salt, gypsum.

III. *Igneous or metamorphosed deposits:*
Certain building stones, diamonds and precious stones, kaolin, some iron ores.

IV. *Mechanical accumulations:*
Placer gold, diamonds, tin, magnetic iron sands.

V. *Vein deposits or lodes.*

Veins are sheets of rocks filling fissures in other rocks.†

Difference between veins and dikes.

Dikes are crevices in the rock filled with molten rocks.
Dikes of sandstone exceptional (see page 186).

Veins are crevices filled with mineral from solution.
False veins are crevices filled from above.
Example: sandstone veins in quarries of anesite at Adalante villa.
These are sometimes called sandstone dikes (see page 186).

If veins are made by minerals filling crevices and cracks in the rocks, it becomes important to understand the forms, sizes, and depths of cavities in the rocks.

Origin of crevices.

I. By torsion.‡ twisting - warping - folding -
II. Earthquake jars when the rocks are under tension.
III. Faults.

* Wadsworth, Proc. Boston Soc Nat. Hist. XXII, 202–3. 1884.
Branner, Cretaceous and Tertiary geology of Brazil. Trans. Amer. Phil. Soc. 1889, XVI, 419–421.
Hayes, Bul. Geol. Soc. Amer. 1897. VIII, 218.
Call, the geology of Crowley's Ridge. Ann. Rep. Geol. Surv. Ark. for 1889. Vol. II, 99–101. Little Rock, 1891.

† Mining geology of the Cripple Creek district, Colorado. By R. A. F. Penose, Jr. 16th Ann. Rep. U. S. Geol. Surv. Part II, 144–150. Washington, 1895.

‡ Daubrée, Géologie experimentale, 307–314. Paris, 1879.

Earthquakes produce joints in rocks but not large crevices in which veins are found.

If a crack is filled up by molten lava it is called a dike.

Rocks run along with axis of anticline & syncline.

IV. Openings along the crests of anticlines and the bottoms of synclines.

Depth of crevices.

Rocks closely confined flow under great pressure.

At certain depths, about six miles, crevices cannot remain open.* Experiments of Adams and Nicholson.†

Veins formed in open crevices must have formed within the zone of rock resistance.

Theory of pressure produced by chemical affinity at the time of the formation of veins.

Theory of osmotic pressure.

Thickness of veins.

Varies from fraction of an inch to many feet.

Forms of veins.‡

May be single or in sets, and parallel.§

Some veins anastamose in all directions.

Vary in size in different parts.

Materials of veins.

Various minerals carried in and deposited from solution.

Banded.

Brecciated.

Occurrence of veins.

More abundant in metamorphosed rocks.

Associated with some mountains.

Mineralizing agencies often more active.

Not always true, though.

The filling of veins.

Theories concerning the source of the materials.¶

I. *From below* (Posepny, Newberry and others).

II. *From above* (Werner and Wallace).

III. *From sides*, or lateral secretions.‖ (Sandberger, Winslow, etc.)

* Flow and fracture of rocks. By L. M. Hoskins. 16th Ann. Rep. U. S. Geol. Surv., 845–874. Washington, 1896.

Metamorphism of rocks and rock flowage. By C. R. Van Hise. Am. Jour. Sci., July, 1898, CLVI, 75–91; Bul. Geol Soc. Amer. 1898, IX, 269–328.

† Science, Jan. 21, 1898, VII, 82–83.

‡ The gold quartz veins of Nevada City and Grass Valley districts, California. By W. Lindgren. 17th Ann. Rep. U. S. Geol. Surv. Pt. II, 158–170. Washington, 1897.

§ Quar. Jour. Geol. Soc., L, plate 27, 658. London, 1894.

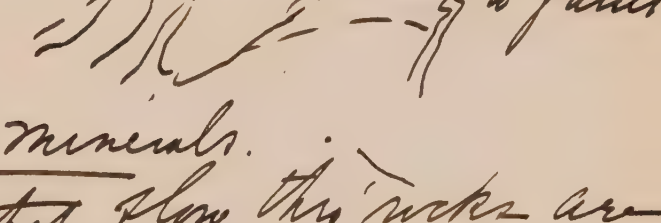
¶ Kemp's ore deposits, 42–55. New York, 1893

‖ Trans. Am. Inst. Min. Eng., 1893, XXII, 634, 735.

Posepny's Genesis of ore deposits, 174–176. New York, 1895.

V Shrinkage due to dolomites
i.e. drying up a marsh - clay
shrinks & cracks. Run zig zag
VI Expansion of rocks due
to pressure -

On crest of anticline where there is
faulting a crevice will be made
in the fault plane.



Veins of minerals.

Waters that flow thru rocks are
charged with minerals - Constantly
they deposit mineral matter & cracks
which were very small at first are
made larger. Crystallization goes on
& spreads out - thus cracks -

Veins ‖ to each other generally some
& part of light temp. & pressure in which
is that dissolving power increases as
temp. & pressure are increased. So at low

Processes of filling.

I. From volatilization, i. e., from gases.
Examples: mercury, sulphur.

II. From hot waters and from solution.
Examples: box-pipe from Comstock lode; hot springs deposits.

III. From deposits by ordinary waters.

*How minerals change in depth.**

Oxides and free gold above.
Sulphides below.

Uncertainties in mining for precious metals, in so far as they depend upon the extent of the ore deposits are due to

I. Irregularity of veins, fractures, or crevices, in which veins form.

II. Irregularity of the conditions of deposition.

III. Irregularities due to displacements since deposition.

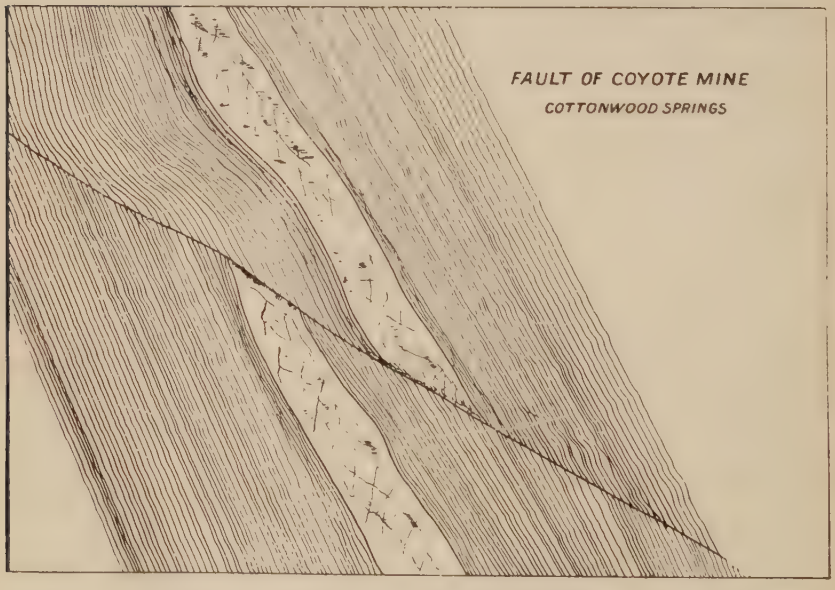


FIG. 30.—A quartz vein displaced by a verticle fault.

The *risks of mining* are due largely to these uncertainties.

If rocks were uniform in texture and composition, and if we knew the conditions and stresses, the cracks could be calculated; but we do not.

* The superficial alteration of ore deposits. By R. A. F. Penrose, Jr. Jour. Geol. 1894, II, 288-317.

"Can you have a dyke in a vein?

2. " " " " vein " " dyke?

3. " a dyke have a dip?

4. " " vein " " " ?

A mother-lode is a group or belt of veins from which the veins branch out. Richness of ore deposits will not continue indefinitely into the earth, because pressure increases with depth + cracks cannot be found -

Certainty of mining bedded deposits.

Coal lignite and gypsum, salt, asphaltum, etc. (See plate XIII.)

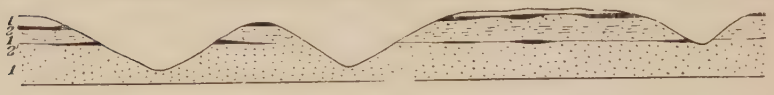


FIG. 31.—Vertical section showing bedded deposits (black) interstratified with horizontal rocks

*South African gold beds.

Terms used.

Lode.
Foot-wall.
Hanging-wall.
Country-rock.
Gangue (quartz common).
Horse.

Placer deposits.

Origin of.
How original quartz veins were discovered.
Diamond placers of Brazil.

SPRINGS, WELLS, AND ARTESIAN WELLS, IN THEIR RELATION TO GEOLOGIC STRUCTURE.

SPRINGS.

The waters of springs are meteoric waters (rain or snow) that have fallen on the earth, soaking into the ground and emerging naturally.‡

Emerge by gravity, *guided by the rocks.*

Accumulations of water occur in rocks having room for water; that is, in porous rocks.

Porosity is due to rock structure and *may be caused.*

I. By spaces between coarse materials.
   The coaser the materials the more the space.
   Hence, water from conglomerates and coarse sandstone.

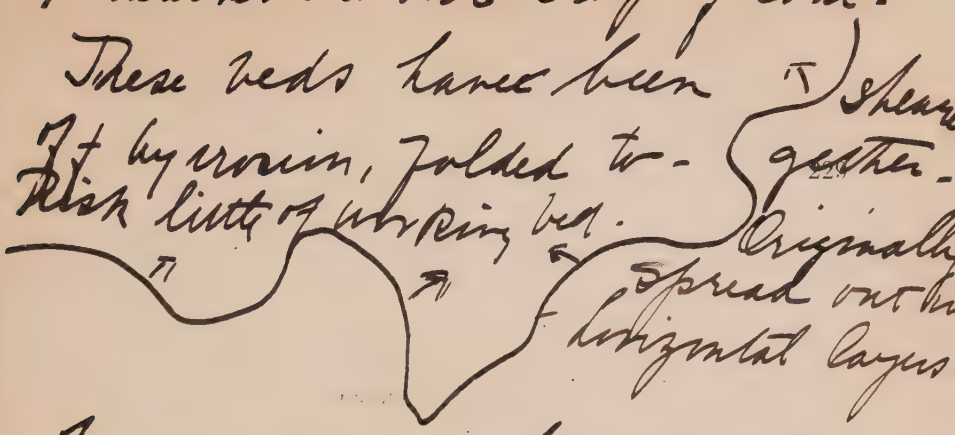
II. By joints or cracks in rocks.
   In shales when it flows through joints.

III. By openings caused by solution and removal of rock.
   As in the caverns of limestone regions.
   Note the size of springs in limestone regions.

IV. By dolomitization, caused by shrinking of rock, and in cracking.

*Gold mines of the Rand. By F. H. Hatch and J. A. Chalmbers. London, 1895.
Les mines d'or du Transvaal. Par L. de Launay. Paris, 1896.

‡ On the percolation of rainfall, see the Water supply of England and Wales. By C. E. de Rance, 8-22. London, 1882.

These beds have been


It by erosion, folded to-
Rich little of working bed.

Vein is used when speaking of smaller branches of deposits, while lode pertains to larger bodies. Origin of Placer deposits- important By a process of freezing & thawing soil all cracked up thus breaking up ore deposit. Water sweeps down & washes away lighter material- In course of time gold will be accumulated in a bed then covered with coarse sand- This places deposit By erosion ore beds have been washed off carrying down stream the metal- Rich placer deposits do not mean there are rich quartz ledges near- years to wash down metal

Water goes where it can flow most easily.
Emergence depends on geologic structure or bedding.

May be caused by
I. Fissures.
II. Faults.
III. Folds.
IV. Impervious strata stopping the downward passage of the water.*

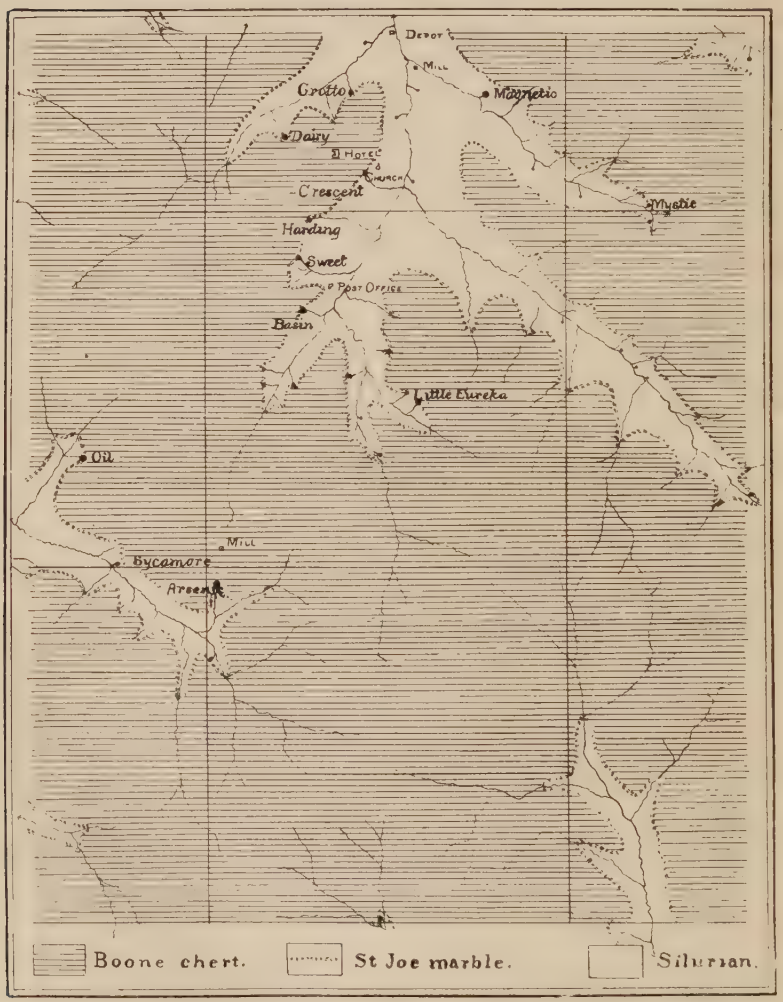
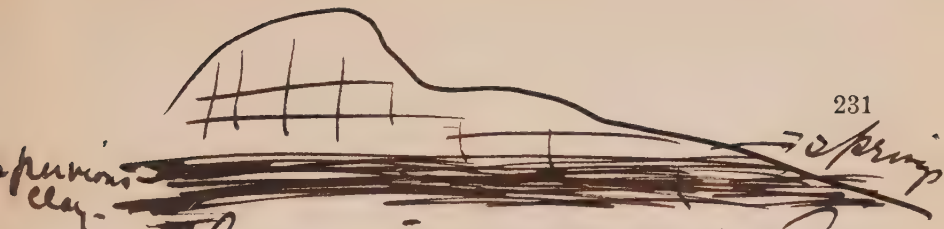


FIG. 32.—Geology about Eureka Springs, Ark., showing the influence of stratigraphy upon the emergence of springs. (Hopkins.)

*T. C. Hopkins, Ann. Rep. Geol. Surv. Ark. for 1890, IV, 345–6. 1893; Amer. Geol., 1894., XIV, 365–8.

Streams have cut down



almost impossible for
water to flow thro' clay

COMMON WELLS.

Wells tap rocks holding accumulated or accumulating underground waters.

Waters accumulate in any openings in rock or soil.

I. Spaces in coarse sediments, gravels, sands.
II. Alluvial lands (owing to position).
III. Pockets in glacial drift.*

The uncertainty of water in the *drift* is due to the irregularity of the bedding of glacial drift.

Why the waters of wells differ even when near each other.

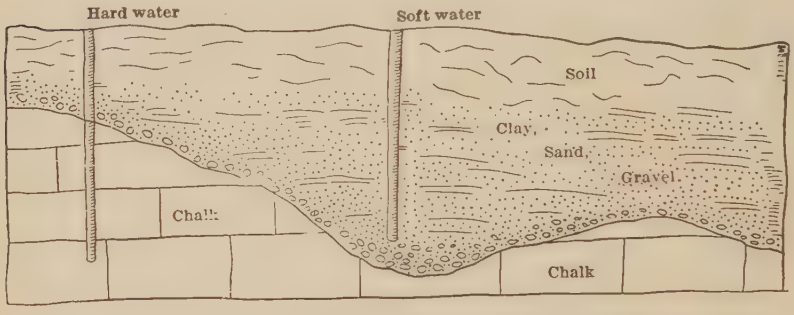


FIG. 33.—Vertical section in the chalk region of Southwest Arkansas, showing why the water of some of the wells are hard, while others are soft.

Why wells are sometimes found in mountain tops.

I. Porosity of containing bed, and a confining bed below.
II. Synclinal structure of mountain.

Structural features always important.

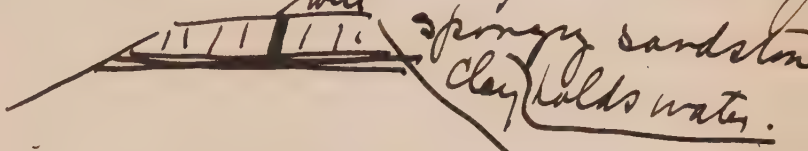
See cases above mentioned.
Synclinal trough south of Stanford University.
Why water is abundant on College Terrace, but not to be had in the foot-hills immediately south of the Quadrangle.
Case of horizontal well in vertical beds.
Where to bore in special cases.

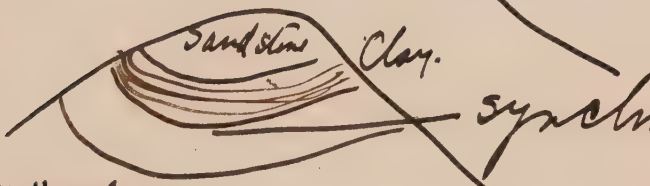
The ebbing and flowing of wells.†

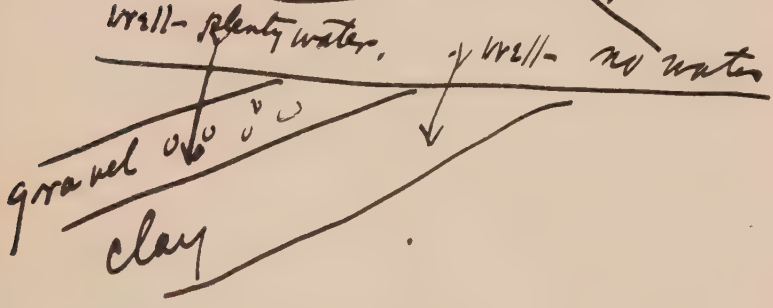
* Water resources of Indiana and Ohio. By Frank Leverett. 18th Ann. Rep. U. S. Geol. Surv. Part. IV. 419–559. Washington, 1897.

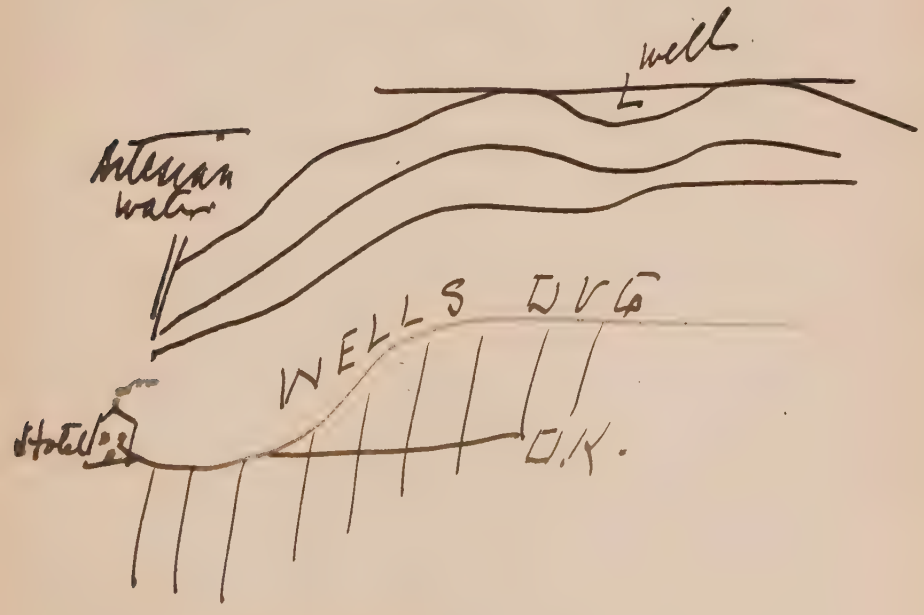
†H. G. Madan, Quar. Jour. Geol. Soc. Aug. 1898, LIV, 301–307.

Sandstone like a sponge takes up water & will not give it out, so easy to tap it.









ARTESIAN WELLS.*

Artesian wells are those from which the water flows.

It has accumulated under *special structural conditions.*

Wide areas usually involved.

Essential conditions.

I. Water-bearing stratum (to hold the water).
   Must be of coarse or porous material.
II. A confining stratum (to keep it in).
   Usually fine silts, especially clays.
III. Head or elevated source (to force it out at opening).
IV. Rainfall at outcrop (to furnish supply).

Origin of the artesian waters of Wisconsin, Dakota, etc.

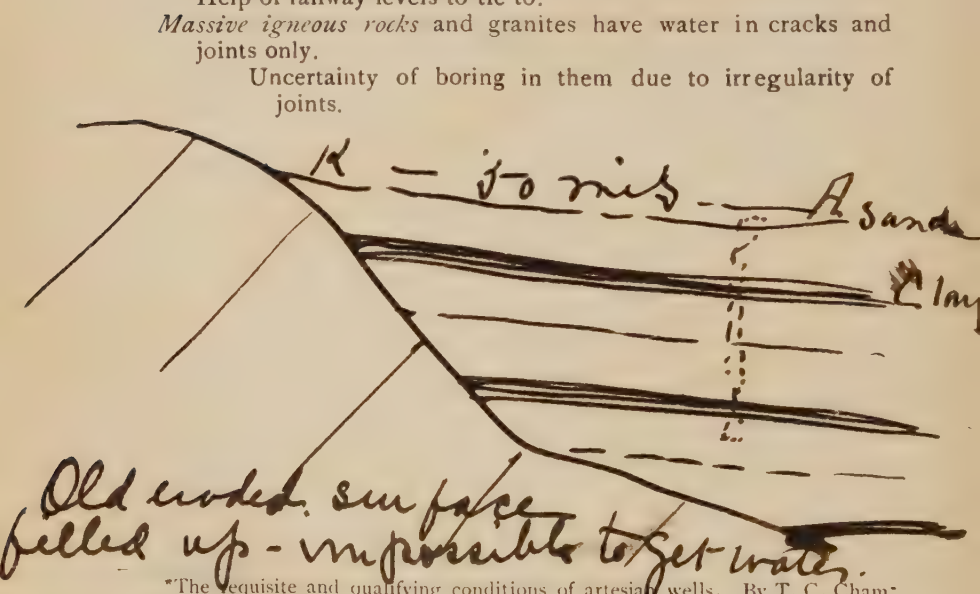
Origin of the Santa Clara county artesian waters.

Importance of determining elevations.

Help of railway levels to tie to.

Massive igneous rocks and granites have water in cracks and joints only.

Uncertainty of boring in them due to irregularity of joints.



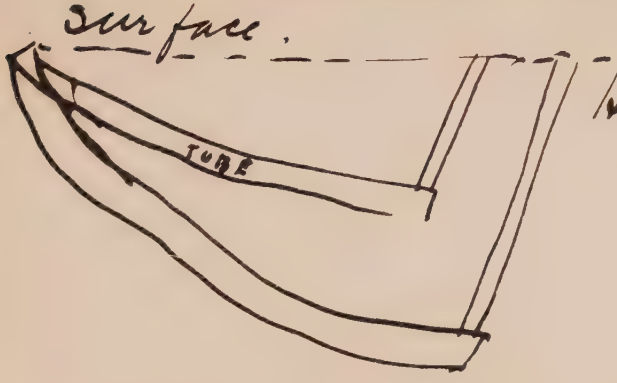
*The requisite and qualifying conditions of artesian wells. By T. C. Chamberlin. 5th Ann. Rep. U. S. Geol. Survey, 125-173. Washington, 1885.

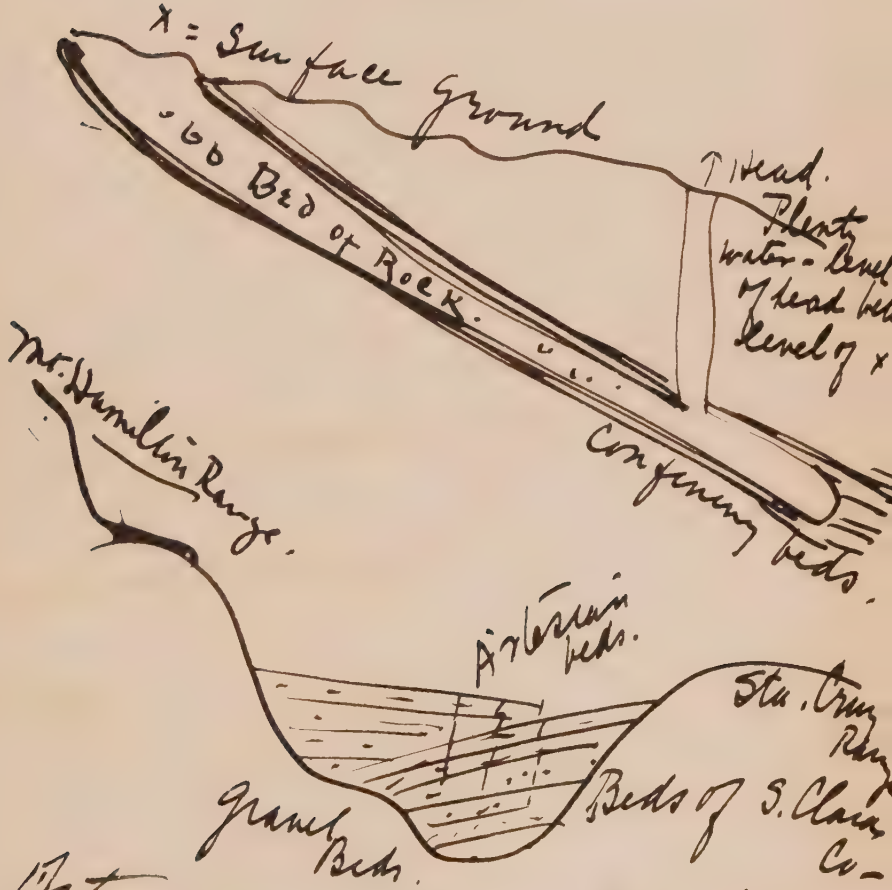
Artesian waters of a portion of the Dakotas. By N. H. Darton. 17th Ann. Rep. U. S. Geol. Survey, Part II, 1-92. Washington, 1896.

New developments in well boring and irrigation in eastern South Dakota. By N. H. Darton. 18th Ann. Rep. U. S. Geol. Survey. Part IV, 561-615. Washington, 1897.

Artesian wells upon the great plains, being the report of a geological commission, etc. Department of Agriculture. Washington, 1882.

Artesian Wells.





Artesian wells sunk will give water easily but valley will be drained of water if wells are continuous

PART III.

HISTORICAL GEOLOGY;

OR

PALEONTOLOGY.*

THE ORDER OF EVENTS AND LIFE AS RECORDED IN THE ROCKS.

Treats of the order and ages of the rocks—*i. e., the history of the earth as shown by the rocks and their fossil contents.*

The history of the earth must be learned:

I. By deductions from the known laws of matter.

II. By the study of the operation of these laws as shown by the rocks.

The laws of matter teach us that:

I. Stratified rocks are laid down in water (except æolian and plant accumulations) in approximately horizontal beds.

II. The oldest beds were laid down first and at the bottom, the newest ones last and on the top.

III. The disturbance of the horizontality and continuity of these beds, and their metamorphism, must have taken place since their deposition.

*Geological Biology. By Henry Shaler Williams. New York, 1895.
Text-book of comparative geology. By E. Kayser. Translated by P. Lake. London, 1893.

IV. If a locality is above water during a given time, no sedimentary beds can be deposited thereon during that period.

V. Inasmuch as the earth's crust is liable to elevation and depression, deposition of sediments at a given place is liable to be interrupted, and we may not expect to find a continuous and uninterrupted deposition at all places, or perhaps at any one place.

VI. The rocks preserve in themselves many evidences of the conditions prevailing and of the geography when and where they were laid down.

VII. The fossils found in a given bed of sediments are the remains of plants or animals that lived when the beds were being deposited. (Except in cases of fragments derived from older beds.)

VIII. The periods of the first appearance and changes in the characters of faunas and floras will be indicated or suggested by the remains of animals and plants preserved as fossils.

IX. In many places the sedimentary rocks have all been removed by erosion, and the history of the place as originally preserved in those rocks has been entirely obliterated.

It is thus evident that the earth's history, where not obliterated by erosion and metamorphism, is to be found both in the *nature and condition of the rocks and in the character of the fossils.*

X. The geological record, therefore, is at best an imperfect one.*

WHAT IS SHOWN BY THE KINDS OF ROCKS.

They are sedimentary, organic, chemical deposits, or igneous. Changes making variation of rocks often affected life, and thus the fossil contents of the rocks.

WHAT THE PRESENT CONDITIONS OF THE ROCKS SHOW.

I. By metamorphism, that they have been affected by metamorphosing conditions.

II. By faulting, that they have been under tension or pressure.

III. By folding, that they have been squeezed.

IV. By dikes, that molten rocks have broken through them.

V. By unconformities, that land conditions, admitting denudation, have intervened.

*Darwin's "Origin of species," chap. X. New York, 1870.
Lyell's Principles of geology, chap. XIV. New York, 1889.
Darwinism. By A. R. Wallace. Chap. XIII. London and New York, 1889.

FOSSILS AND THEIR USES.*

WHAT DIFFERENT KINDS OF FOSSILS SHOW.

Salt-water forms show salt-water conditions.
Brackish water forms indicate brackish water conditions.
Fresh-water forms indicate fresh-water conditions.
Deep-water forms show deep water.
Shallow water forms show shallow water.
Cold water forms show cold water.
Warm water forms show warm water.
Swamp life indicates conditions of swamps.
Plants may have been washed down in fresh water.
Trees and big stumps show land conditions. (See plate XI.)
Life peculiar to cold climate indicating cold.
Life peculiar to warm climate indicating warm.
Changed conditions produce variation of faunas and floras.
These conditions limit the range of animals and plants on earth, and hence physical changes produced different conditions favorable to different forms of life.
In these changes many forms were crowded out and exterminated.

MARINE DEPOSITS.

Littoral.
Deep water.
Abysmal.
Animals and plants having hard parts often have them preserved.
Bones of fishes, whales, crabs, corals, shells.
Animals and plants without hard parts are seldom preserved as fossils.
Examples: jelly fishes, slugs, soft algæ.
No remains are preserved save when the conditions are favorable.

LAND DEPOSITS.

Land animals and land plants decay for the most part, unless they fall in water or mud, or are washed to the sea and buried by sediments.
In lakes; peat bogs; river mouths.
Things preserved in mud or clay.
Bones, skeletons, teeth, scales of fishes.
Impressions of plants, trunks, bark, and leaves; rain-prints, ripple-marks.
Wings of insects.
Birds, bird tracks.
Cave deposits; mammals.

*Notes on the silicification of fossils. By T. S. Hunt. Canadian Naturalist; 2nd ser. I. 46–50. Montreal, 1864.

Fossils, their nature and interpretation. Geological Biology. By Henry Shaler Williams. 78–110. New York, 1895.

The process of fossilization. 48th Ann. Rep. N. Y. State Museum, II., 211–215. Albany, 1895.

Fossils and fossilization. By L. P. Gratacap. Amer. Naturalist, Nov., 1896. XXX, 902–912; Dec., 1896. XXX, 993–1003; Jan., 1897. XXXI, 16.

Fossils may therefore be:

I. Mould or impression of the outside parts of animal or plant.
II. Cast of the inside.
III. The thing itself, or its hard parts, preserved.
IV. The form of the thing itself replaced by some mineral.
Examples: silicification of wood, shells, etc.
(See plate XII.)

Relative values of fossils.

Conditions of preservation better under the sea than on land.
Hence, marine forms are more abundant as fossils than land forms, and more important.
Some kinds of fossils, such as protozoa, sponges, lingulas, are found in rocks of all ages.
Others are very limited in geologic distribution.
Land organisms have small chance of preservation.
Highly developed and specialized mammals are of limited range.

THE GEOLOGIC COLUMN.

All divisions are more or less artificial, for periods often grade insensibly into each other.

What is meant by "the geologic column."
The piling up of rocks upon each other.
The thickness of the beds varies greatly at different places.

Attempts to divide the column according to:

I. *Lithologic characters.*
Limestones, sandstones, clays; are contemporaneous and intergrade.
Sedimentary and igneous rocks contemporaneous.
All occur from the bottom to the top.

II. *Color.*
"Old Red" and "New Red" abandoned.
Color is of little importance; the same ones may occur anywhere in the column.

III. *Mineral contents.*
Minerals are often introduced as veins in rocks of any age.

IV. *Order in which the rocks are found.*
This order is not everywhere the same.
Sometimes the newest rocks rest on the oldest; sometimes on the very new ones.
Difficulties of chronologic division increased by overturning, metamorphism, faulting, erosion, and interruptions in the deposition of the beds.

CORRELATION OF BEDS IN SEPARATE REGIONS.

What is meant by correlation.

In making geologic divisions, it is necessary that the beds at one place shall be correlated with those of another, or their equivalents determined.

Precautions necessary in making correlations.

I. That the rocks are not overturned.
This is possible in regions of sharp folds and steep dips.

II. That they are not faulted.
This is common in some tilted regions.
May occur in horizontal strata bringing similar beds opposite each other.

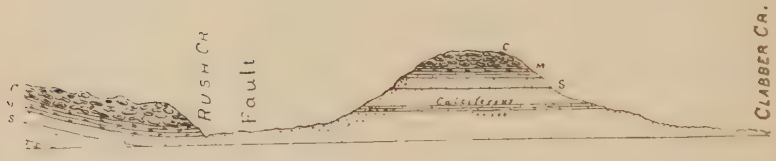


FIG. 34.--Section across a fault on Rush creek, Ozark mountains. The sandstones at s. are let down until they appear to be continuous with the older ones below the calciferous strata.

III. Look out for unconformities.

IV. But conforming beds may not be contiguous deposits, and intervening ones may be omitted.
Color, texture, and mineralogic composition of bed can only be used within short distances.

Use of fossils in the correlation of rocks.

Beginnings of paleontology by William Smith.

Life on the globe has been changing from the first.

Each period has had its own forms.

This progress has involved constantly closer proximity to existing forms.

Hence, identity of fossils shows that the beds containing them have *approximately* the same age.

In every country fossils show the same general order of succession.

Why identity is only approximate.

1. Slow change of life at one place.
2. Spread of life forms over the globe from one point.
3. Life zones due to climatic differences.
4. Life zones due to depth and character of water.

Use of fossils in the study of geographic changes.

Former connection of America with Asia.

Fossils as evidences of climatic changes.

Conditions of coral growth and the distribution of fossil corals.
Fossil palms found in cold climates.

Uses of the knowledge of fossils in mining geology.

In looking for coal or other rock deposit or mineral known to be at certain horizons.

Lead and zinc in the Ozark mountains in Silurian rocks below Carboniferous.

Detection of faults.

Detection of overturns.

Detection of geologic breaks.

Location of coal beds in folded areas.

The coal beds about Magazine mountain and Mt. Nebo, Ark.; the Bernice basin in Pennsylvania.

Stratigraphy will do the same, but it can not always be worked out over large areas.

Examples: Pennsylvania, Illinois, East Tennessee, and Alabama coals.

SUBDIVISIONS OF THE GEOLOGIC COLUMN.

Characteristic life.				
Man.	Psychozoic	Recent.		
Mammals.	Cenozoic.	Pleistocene.	Terrace. Champlain. Glacial.	
		Tertiary.	Pliocene. Miocene. Eocene.	Neocene.
		Cretaceous.	Upper. Lower.	
Reptiles.	Mesozoic.	Jurassic.	Upper. Middle. Lower.	
		Triassic.	Upper. Middle. Lower.	
Acrogens.	Paleozoic.		Permian.	
Amphibians.		Carboniferous.	Coal Measures.	
			Lower Carboniferous.	
Fishes.		Devonian.	Catskill. Chemung. Hamilton. Corniferous. Oriskany.	
	Silurian.	Silurian or Upper Silurian.	Lower Helderberg. Salina. Niagara.	
		Ordovician or Lower Silurian	Trenton. Canadian.	
Invertebrates.		Cambrian.	Potsdam. Acadian. Georgian.	
	Archæan.	* Algonkian.	Keweenawan. Huronian.	
		Archæan.	Laurentian.	

* Van Hise places the Algonkian as a separate formation between the Archæan and Paleozoic.

ARCHÆAN PERIOD.

Sometimes called Azoic and Agnotozoic.

Archæan time may be divided into three periods or eras.

I. Era of the molten globe.

II. Era of the cooling crust: condensed vapors covered the earth with waters.

If any part of the crust remained above water, erosion began.

III. Temperature lowered to a point admitting the simplest forms of vegetation.

This was the beginning of life on the earth.

The rocks formed during Archæan time are the lowest ones accessible to us, and underlie all others.

Evidences of life in Archæan rocks.

No fossils are found in Archæan rocks, but it seems reasonable to suppose that life began during Archæan time, for the following reasons:

1. Evidences of life are abundant in the next higher rocks—the Cambrian; it is therefore reasonable to suppose that life had its beginning somewhat earlier.
2. Limestones (marbles) in the Archæan: probably of organic origin.
3. Iron ores abundant in Archæan; accumulated through the agency of organisms and organic acids in bogs, lakes, and meadows.*
4. Graphite and plumbago in Archæan rocks believed to be derived from plants.†
5. Apatite is a phosphatic rock. Other forms of phosphate rocks are of organic origin, and the apatite deposits abundant in Archæan rocks are probably metamorphosed forms.
6. Presumptive evidence.

The existence of animals in the Cambrian.

Animals live on plants; plants must have existed first; animals of Cambrian must have had Cambrian plants, and those probably had Archæan ancestors.

The plants could live in very hot waters.

Distribution of Archæan rocks in North America.

Economic deposits of the Archæan.

Iron ores of the Adirondacks in New York.
Iron ores of the Lake Superior region.
Graphite.
Apatite of Canada.
Marble beds.
Granites for building.

*Phillips' Ore deposits, 2nd ed. 35–43. London, 1896.

†On the graphite of the Laurentian of Canada. By J. W. Dawson. Canadian Naturalist, new series. V, 13–20. Montreal, 1870.

PALEOZOIC PERIOD.

Nature of the paleozoic rocks.
Mostly marine sediments.
Some fresh-water and land deposits.
Life of the paleozoic times.
Chiefly marine invertebrates, and
Cryptogamic plants (ferns, club-mosses, horse-tails).
Paleozoic rocks are divided into (beginning below) Cambrian, Ordovician (or Lower Silurian), Silurian (or Upper Silurian), Devonian, and Carboniferous.

CAMBRIAN.

The word derived from "Cambria," the ancient name of Wales, where these rocks were first studied.
The lowest and oldest rocks that contain recognizable fossils.

Fossils.

No plants certainly known; by inference, they must have existed, to supply food to the abundant animal life.
Animals include, principally, sponges, hydrozoa (graptolites), worms, echinoderms, trilobites, gasteropods, pelycypods, and brachiopods.

ORDOVICIAN (or Lower Silurian).

Name derived from "Ordovici," an ancient tribe of Wales, where these rocks occur.
The name Silurian from "Silures," also an ancient tribe of Wales.

Fossils.

The fossils of the Ordovician show marked advance in life.
Some forms, as graptolites, and trilobites, culminated and began to decline during this period.
Corals rather abundant.
Centipedes, the first known land animals.
Bivalves and gasteropods increase greatly in size and number.
Cephalopods appeared in the Cambrian, but are abundant in the Ordovician.

Economic products.

Lead ore of the Galena limestone of Wisconsin, Iowa, and Illinois.
Petroleum and gas from the Trenton limestone of Ohio and Indiana.
Relation of the "Trenton rock" to these products.
Marbles of Vermont, Massachusetts, New York, and Tennessee.

SILURIAN (or Upper Silurian).

Silurian rocks in North America are thicker along the Appalachian mountains, and thin out toward the west.

An inland sea with its eastern margin near the eastern border of the continent.

Fossils.

Scorpions and insects.

Some plants, but not abundant.

Sharks among the earliest vertebrates.

Crinoids increased in numbers.

Bryozoa and brachiopods continue abundant.

Pteropods smaller and less abundant.

Graptolites and trilobites less abundant.

Climate.

The nature of the fossils suggest warm or temperate seas.

The occurrence of extensive salt beds in New York and Canada shows that salt water must have been concentrated there. Probably arid at that time.

Economic products.

Clinton red fossil iron ore along Appalachian mountains from New York to Alabama.

Joliet building stone of Illinois.

The brines and rock salt of New York and Canada from the *Salina*, or salt group, of the Silurian.

Gypsum accompanies the salt, used as fertilizer or "land plaster."

Hydraulic cement; the "Rosendale," made near Rondout, N. Y.

DEVONIAN.

Name from county Devon, in England.

Distribution of Devonian rocks in North America.

Geographic interpretation of this distribution.

The rocks are sandstones or shales in New York and the Appalachians, but limestones in Ohio and Illinois.

Thins out westward.

Fossils.

Brachiopods the most abundant fossils.

Corals very large and abundant; reef forming.

Vegetation very abundant.

Fishes remarkable for numbers and size.

Some Ohio fishes 18′ long, 6′ across head, and 3′ through.

Graptolites and cystids nearly extinct.

First amphibians.*

*O. C. Marsh, Am. Jour. Sci., Nov. 1896. CLII, 374.

Economic products.

Oil and gas of Pennsylvania and New York.
Flagstones.
Phosphates of Tennessee and Arkansas.
Hydraulic limestones at Louisville, Ky.

CARBONIFEROUS.

Name from the coal it contains.

The principal divisions are *Permian*, *Coal Measures*, *Lower Carboniferous.*

LOWER CARBONIFEROUS.

Beginning at the base the rocks of the Lower Carboniferous are mostly limestones, and contain marine fossils.

The area of these rocks must, therefore, have been covered by the sea at the time of their deposition.

Distribution of Lower Carboniferous rocks in North America.

Fossils.

Crinoids very abundant; some rocks almost made up of the broken stems.
Corals and brachiopods abundant.
Bryozoa; *Archimedes.*
Some amphibians.
Trilobites decline.

Economic products.

Salt brines, Michigan.
Marble of Tennessee and Arkansas.
Building stones of Indiana.*

COAL MEASURES, OR CARBONIFEROUS PROPER.

Rocks are conglomerates, sandstones, shales, and coal.

These rocks have a total thickness of 16,000′ in Nova Scotia; 23,780′ in Arkansas.

No definite order of arrangement over the whole area, but locally the order is constant.

Examples: Pottsville conglomerate and Mauch Chunk, red shale in Pennsylvania.

Extent of the Coal Measures in North America.

The abundance of coal and of fossil plants shows that the land was covered by extensive marshes for long periods.

The occurrence of marine fossils, interstratified with coal beds, show that the land occasionally sank beneath the sea.

Carbon in the coal derived from the atmosphere.

*Hopkins and Siebenthal, 21st Ann. Rep. Geol. Surv. of Indiana. Indianapolis, 1896.

Atmosphere not necessarily heavily charged.*
Carbon from the rocks constantly renewing it.

Fossils.

Plants are most abundant; well preserved in the clays underlying the coal beds.
Ferns, club mosses, pines.
Insects abundant; cockroaches, neuropters.
Spiders.
Amphibians.

Economic products.

Coal most important.
Beds vary from thin laminæ, up to 60′ at Pottsville, Pa.
Anthracite, bituminous, Cannel.
Iron ores.
Fire clays associated with coal.

PERMIAN.

Name from the province of Perm, Russia.
The division between the Carboniferous and Permian is not strongly marked in North America.
Distribution of the rocks in North America.
Retreat and shallowing of the Carboniferous seas.
The existence of beds of salt in Southwest Kansas shows that an arm of the sea was there cut off and dried up.
The structure and distribution of the rocks show that there were great geographic changes in North America at the end of the Permian.

Fossils.

Crinoids much less abundant than in the Carboniferous.
The few trilobites of the Permian disappear at the end of this period.
First appearance of reptiles.

Economic products.

Gypsum and salt in Kansas.

MESOZOIC PERIOD.

The mediæval period of the earth's history.
The precise measurement of the length of the periods is not possible.
The Mesozoic is divided into Triassic, Jurassic, and Cretaceous.

* Microscopical light in geological darkness. By E. W. Claypole. Trans. Amer. Microscopical Soc., 1897. President's address.

TRIASSIC.*

Name derived from the German rocks, which consist of three marked subdivisions.

In North America the Triassic beds are marine on the Pacific coast, fresh and salt lake deposits in the Rocky mountain region, and marine on the Atlantic coast.

Distribution of the rocks.

Red sandstones of Massachusetts, Connecticut, New Jersey, Pennsylvania, Maryland, Virginia, and North Carolina.

Some coal beds in Virginia and North Carolina.

Fossils.

The fossils of the interior basin show the waters to have been lakes.

Those of the Pacific coast are marine.

Cystids and blastoids had disappeared.

Brachiopods had greatly declined.

Pelycypods much more abundant than before.

Cephalopods greatly increased in numbers.

Amphibia reached their greatest importance.

Reptiles much more abundant.

First appearance of mammals.

Economic products.

Gypsum and salt of the interior basin, Kansas.

Coal beds of Virginia.

Brownstone so extensively used in eastern cities for buildings.

Potomac marble of the Capitol columns at Washington.

JURASSIC.

The name from the Jura mountains in Switzerland, which are of these rocks.

No Jurassic rocks known in eastern North America.

A mediterranean sea, or salt lake, in the Rocky mountains and Great Basin region.

Marine deposits of California and Oregon.

Fossils.

Cephalopods culminate in the Jurassic.

Reptiles were very abundant; some of them winged; many of enormous size.

Earliest birds known; toothed birds.

Economic products.

The gold veins of the Pacific slope are largely in Jurassic slates. These veins are not Jurassic in age, but were formed subsequently.

* Bul. 85, U. S. Geol. Survey. By I. C. Russell. Washington, 1892.

CRETACEOUS.

Name from Latin *creta*, chalk.

The chalk deposits of England belong here.

Distribution of Cretaceous rocks in North America.

The geographic changes of the lower Mississippi valley, that preceded the deposition of the Cretaceous beds.

Some of the interior beds were deposited in fresh water ; those of the coasts are marine.

Fossils.

The change among plants is most marked.

Appearance of dicotyledonous plants, with representatives of oaks, maples, elms, etc.

First palms known.

Bony fishes very abundant.

Crocodiles, mammals ; some of the birds had teeth.

Economic products.

Greensand marles and potters' clays of New Jersey.

Chalk deposits of Arkansas and Texas.

Gypsum beds of Iowa.*

Coal deposits of Puget Sound, Colorado, Utah, Wyoming, Montana, and New Mexico.

In Colorado these coals are changed to anthracite.

Auriferous conglomerates in northern California.

CENOZOIC PERIOD.

The Cenozoic rocks are known as Tertiary, and Quaternary or Pleistocene.

Mammals became the most important animals.

TERTIARY.

Origin of the name : Paleozoic rocks formerly known as Primary ; Mesozoic as Secondary ; later ones as Tertiary.

Name retained, though not used in its original sense.

Divisions of the Tertiary : Eocene, Miocene, Pliocene.

Of living shells { 50% to 90% are Pliocene. / 30% are Miocene. / 5% to 10% are Eocene.

Distribution of the seas on the Atlantic and Pacific coasts ; the interior basins.

Fresh water Pliocene beds of the Santa Clara Valley resting on marine beds.

The crustal movements of the Pacific coast.

Warm climate indicated by plant remains as far north as Greenland.

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* Gypsum deposits of Iowa. By C. R. Keyes. Iowa Geol. Survey, III, 259–304. Des Moines, 1895.

Fossils.

The Tertiary is known as the Era of Mammals; but the Tertiary mammals are all extinct.
Some gigantic. Horses.
Insects, beetles, butterflies.
Conifers, palms.
Birds abundant.

Economic products.

Auriferous gravels of the Sierras.
Diatomaceous earths of California and of Richmond, Va.
Phosphate rocks of Florida, and of South Carolina.
Lignite of Arkansas, Texas, Mississippi, California, and Alaska.
Iron ores.
Greensand marles, and potters' clays of the South.

PSYCHOZOIC PERIOD.

PLEISTOCENE, OR QUATERNARY.

Man appeared during this period, or possibly even earlier.*
Association with extinct mammals.
Chiefly characterized by glaciers that covered a large part of northern Europe and the northern part of North America.
Climate not necessarily very much colder; decrease of 5° in Europe would bring the glaciers of the Alps down to Geneva.
Centers of distribution of ice.
Area covered at the greatest development of the ice.
Evidences of glaciation; direction of movements.
Thickness of the ice.
Withdrawal of the ice.
Evidences of interglacial epochs.
The Wabash drainage; Mohawk valley drainage; St. Lawrence drainage.
Lake Agassiz and its history.
Evidences of elevation and depression.
Effect of glaciation on the topography.
Effect of glaciation on man.
Extinct gigantic mammals.†

*On the Pithecanthropus erectus. By O.C. Marsh, Am. Jour. Sci. Feb., 1895, CXLIX, 144–147; June 1896, CLI, 476–482.

† Mammoth and mastodon remains about Hudson Bay. By R. Bell. Bul. Geol. Soc. Amer. 1898. IX, 369–390.

PRIMITIVE MAN.*

Man must have originated in the tropics, where the climate is not severe, where fruits, nuts, and berries are to be found all the year round; and on the sea shore where fish, mollusks, and crustaceans may be had at all times for food.

Deductions from Zoology concerning man's character and appearance are matters of inference.

Geologic evidences found in the rocks consist of:

I. Works preserved.
II. Skeletal remains preserved.

Nature of evidence of preservedfoot prints.
On Carboniferous rocks on the Ohio river.
On lava in Central America.

Human Relics.

Character of the relics.

I. Flint implements: arrow heads, knives, spears, chips.
Rejects.
Cache forms.
Specialized forms.†
Methods of manufacture.‡
Quarries.§
II. Stone axes, pestles, mortars.
III. Carvings on bones and rocks.
IV. Bone and shell implements and ornaments.
Needles and fish-hooks.
V. Pottery.
VI. Stone structures.
VII. Human bones.

Where these relics are found.

I. In caverns.
Engis skull and bones, found beneath stalagmitic crust in cave near Liege, Belgium, associated with those of extinct animals.

*The geological evidences of the antiquity of man. By Sir Charles Lyell. Third ed. London, 1863, Second Amer. ed., Philadelphia, 1863.

The origin of civilization and the primitive condition of man. By Sir John Lubbock. New York, 1871.

Relation of primitive peoples to environment, illustrated by American examples. By J. W. Powell. Smithsonian Report for 1895, 625-637. Washington, 1897.

Influence of environment upon human industries or arts. By Otis T. Mason. Smithsonian Report for 1895, 639-665.

†Distribution of stone implements in the tide-water country. By W. H. Holmes. Amer. Anthropologist, Jan. 1893, VI, 1-15.

‡American Anthropologist, 1895, VIII, 307.

§Indian jasper mines in the Lehigh hills. By H. C. Mercer. Amer. Anthropologist, Jan. 1894, VII, 80-92.

Neanderthal skull, in cave near Düsseldorf; probably exceptional in character.

In southwest France in cave with drawings of mammoth, etc.

II. In peat bogs.

Preservative action of the peat.

III. In river and lake beds.

Draining of Haarlem lake; relics found.

The Calaveras skull in the auriferous gravels of California*

Skull under lava cap of Table Mountain.

Many human relics reported from the auriferous gravels.

IV. In the glacial drift and loess.

In Europe man preceded the glacial epoch.†

Evidence of his relations to the glacial epoch in North America is doubted.‡

V. Shell heaps.

Mounds of waste or kitchen middings.

Sites of ancient settlements.

Castro mound; similar heaps abundant in the Santa Clara valley and on the coast.

VI. Burial mounds or cemeteries.

Marajo burial mounds at the mouth of the Amazon, and the pottery from them.

Generalization.

All the facts in our possession go to show that primitive man was a savage, and that his development in civilization and the arts has been a gradual one.

LENGTH OF GEOLOGIC TIME.**

Difficulty of stating geologic time in years.

* The auriferous gravels of the Sierra Nevada of California. By J. D. Whitney, 258–288. Cambridge, 1880.

† Man in relation to the glacial period. By Dr. H. Hicks. Nature, Feb. 24, 1898. LVII, 402.

‡ Holmes, Jour. Geol. 1893, I, 15–37; 147; several papers in Proc. Amer. Asso. Adv. Sci., 1897, XLVI, 344 390.

See also page X of this syllabus.

** The length of geologic time. By H. L. Fairchild, Proc. Rochester Acad. Sci. 1894, II, 263–266.

Some geological evidence regarding the age of the earth. By J. G. Goodchild, Proc. Roy. Phys. Soc. Edin. 1896, XIII, 259–308.

Geological biology. By H. S. Williams, 55–65. New York, 1895.

Rate of the recession of waterfalls.

Age attributed to the Falls of St. Anthony, Minn.
Method of computation.*
Efforts to compute the age of the Niagara gorge.†
Uncertain elements in the computation.
Varying thickness of the beds.
Different heights of the falls.
Different amounts and varying character of the water.

Rate of erosion and deposition.

Rate of erosion over the			
Mississippi basin is	1′	for	6,000 years.
Ganges basin	1′	"	2,358 "
Hoang-Ho	1′	"	1,464 "
Rhone	1′	"	1,526 "
Danube	1′	"	6,846 "
Po	1′	"	729 "
Mean	1′	"	3,090 "

Ratio of sea bottom to land is 145 to 52, or say 2.8 times as much water as land.
The deposition of one foot of sediment would require 8,652 years.
The whole of the sedimentary beds since Archæan would, *at this rate*, require 130 millions of years. ‡

*Rate of cooling.***

Calculated from the rate of cooling rock, the age of the earth is estimated at 24 millions of years.

Rate of growth of corals and limestones.

Estimates from the rate of deposition of limestones, etc., lead Mr. Goodchild to estimate the age of the earth since the beginning of Cambrian time at 704 millions of years.
The estimates of the age of the earth since it was in a molten condition, stated in years, vary all the way from 3 million to 2,400 million years.

" Time is as long as space is broad."

*N. H. Winchell, The geology of Minnesota, II, 313–341. St. Paul, 1888.
† Niagara Falls and their history. By G. K. Gilbert. Physiography of the United States, 203–236, New York, 1897. Brief Bibliography.
‡ Nature, 1895, LI, 533–607.
** The age of the earth. By Clarence King. Amer. Jour. Sci. 1893. CXLV. 1–20.
On the age of the earth. Nature. Jan. 3, 1895. LI, 224–227; 438–440.

PART IV.

PHYSIOGRAPHY,

OR

TOPOGRAPHIC GEOLOGY.*

Topographic geology treats of the surface features of the earth in their relations to geology.

Topographic forms are produced by constructive, destructive, and modifying, agencies acting upon the rocks of the earth's crust. The forms may be classed as:

I. *The major relief, or the continental masses and ocean basins.*

II. *The minor relief, or the details of the topography.*†

THE MAJOR RELIEF.

The broad continental and oceanic features of the earth are due to vertical movements of large areas.

These movements are very gradual.

* The physiography of the United States. By Powell, Shaler, Russell, etc. New York, 1897.

Physiographic types. By Henry Gannett. Folio I. Physiography. Topographic Atlas of the United States. Washington, 1898.

† Penck gives a genetic classification of topographic forms on pages 14–17 of *Die Geomorphologie als genetische Wissenschaft.* Sixth International Geographical Congress, London, 1895.

See also the classification of geographic forms by genesis. By W. J. McGee, Nat. Geographic Mag., 1888, I, 27–36.

Theories of the causes of mass movements.

I. Loading and unloading.
The theory of isostacy.*

II. Unequal contraction of the globe.
Theory of the early cooling of the plateaus.
Deeper cooling along depressions.
Theory of differences of materials.
Daubrée's experiments with rubber.†

III. Early tidal action.
Tendency for early folds to be permanent.

OCEAN BASINS.

Relations to the life of the globe.‡
Relations to land areas.
Modification.
By deposition:
I. Of mechanical sediments.§
II. Of organic sediments.
III. Of eruptive materials.
By elevation and depression.

Probable instability of continents and ocean basins.

Suggested by faunal migrations.
Suggested by elevation of marine sediments, which is as great as the depths of the oceans.‖

MOUNTAINS.

The great masses of mountain systems are due to differential elevation; while the details of mountain sculpture are produced chiefly by erosion. (See plate XIV.)

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* For references and discussion, see Earth movements. By C. R. Van Hise. Trans. Wis. Acad. Sci. 1898. XI, 469–475.
The great valley of California, a criticism of the theory of isostacy. By F. L. Ransome, Bul. Dept. Geol., Univ. Cal , I, 371–428. Berkeley, 1896.
Wallace's Maylay Archipelago, 9, foot note. London and New York, 1894.
U. S. Coast Survey, 1894, pt. II, 51–55. Washington, 1895.
Dawson, Quar. Jour. Geol. Soc. 1888. XLIV, 815.
Nature. July 16, 1896. LIV, 256.
An hypothesis to account for the movements in the crust of the earth. By J. W. Powell, Jour. Geol., VI, 1–9. Chicago, 1898.
Gilbert, Bul. Phil. Soc. Washington, 1895. Vol. XIII, 61-75.
Gilbert. Bul. Geol. Soc. Amer. 1893. IV, 179-190.

† Daubrée, Géologie experimentale, 585.

‡ J. P. Smith, Jour. Geol. 1895. III, 384–495.

§ Milne, Lond. Geogr. Jour. 1897. X, 259-289.

‖ See references in Geikie's text-book of geology. 3d edition, page 1070. London and New York, 1893.
Gilbert, Bul. Geol. Soc. Amer. 1893, IV, 187.
La question de la permanence ou de l'instabilité des grandes depressions océaniques. Par F. Prien. Annales de Géographie, III, 173-182. Paris, 1893-4.

Grand Cañon of the Colorado. Mountains and peaks left by the erosion of horizontal strata.

Types of mountains.

I. Mountain chains.
II. Isolated peaks.

MOUNTAIN CHAINS.

Theories of their origin.*

I. Arching of the rocks.†
II. Rise of isogeotherms through sediments.
III. Outflows of lava.
  A. Due to relief of pressure by arching.
  B. Due to relief by tensile movements.
  The fusion point lowered in both cases.
IV. Permanency of folds, however produced.
V. Faults.
  Location of faults of California with reference to the Sierras and Coast ranges.‡ (See plate XVIII.)

ISOLATED PEAKS.

I. Culminating points in mountain chains.
II. Constructed by volcanic ejectamenta.
  San Francisco mountains, Flagstaff, Arizona.
  Jorullo, Mexico, made in a night (1,692 feet§).
III. Mountains or peaks left by circumdenudation.
  Enchanted mesa and the buttes of that type.
  (See also page 266 and plate XV.)

MINOR RELIEF.

Relief forms may be built up by construction, may be produced by some modification or superinduced structure, or they may be the results of destructive agencies acting upon land masses. The agencies may therefore be classed as *constructive*, *modifying* and *destructive*.

I. CONSTRUCTIVE AGENCIES AND THE FORMS THEY PRODUCE.

Subaqueous forms.

Widespread deposits.
Deltas (see p. 66).
Bars (see p. 64).
Barrier beaches (see p. 64).
Spits (see p 64).

* The origin of mountain ranges. By T. Mellard Reade. London, 1886.
Orographic geology; or the origin and structure of mountains. By G. L. Vose. Boston, 1866.

† Willis, 13th Ann. Rep. U. S. Geol. Surv., pt. II, 249.

‡ The great Sierra Nevada fault scarp. By H. W. Fairbanks. Pop. Sci. Monthly, Mar., 1898. LII, 609-621.

§ Voyage de Humboldt et Bonpland. Atlas pittoresque. 242-4. Paris, 1810.

Katzimo, or the Enchanted Mesa, a hill of circumdenudation, 430 feet high, near Acoma, New Mexico

—From Land of Sunshine Magazine.

Emergent forms.

Transformation of deltas, bars, barriers, and spits into dry land.*
Silting up of fjords.

Example: Oceanside, California.

FIG. 35.—Sketch map showing the submerged and choked up valleys near Oceanside, California.

Silting up of lakes; salt marshes and fresh water marshes.†
Formation of storm beaches; coral islands.

Subærial forms.

Volcanic ejectamenta.

Cinder cones.

Near Flagstaff, Arizona.

Lava cones.

Examples: Shasta; Marysville buttes.

Laccolitic mountains.‡

Lava sheets.

Example: Wyoming, Idaho, etc.

Calcareous and siliceous deposits formed by certain springs and streams. (See plate XVI.)

* An interesting case, partly attributable to elevation and partly to emergence from delta accumulations, is that of the Isthmus of Suez filled in as a part of the Nile delta and separating Asia from Africa. See Hull's Survey of Western Palestine, 72.

† Fresh-water morasses of the United States. By N. S. Shaler. Tenth Ann. Rep. U. S. Geol. Survey. 261–339. Washington, 1890.

‡ Geology of the Henry mountains. By G. K. Gilbert. The laccolitic mountain groups of Colorado, Utah, and Arizona. By W. Cross, 14th Ann. Rep. U. S. Geol. Sur. 157–241. Washington, 1895.

PLATE XVI.

Minerva terrace, Mammoth Hot Springs, Yellowstone National Park. Carbonate of lime deposited by the combined action of plant life, evaporation, and the escape of carbon dioxide.

II. DESTRUCTIVE AGENCIES.

I. Atmosphere, by means of:
   1. Atmospheric moisture.
   2. Winds.
   3. Changes of temperature.

II. Water in form of:
   1. Rain.
   2. Springs.
   3. Streams.
   4. Waves.
   5. Glaciers.
   6. Tidal currents.*

THE FORMS PRODUCED BY DESTRUCTIVE AGENCIES, AND THE FACTORS DETERMINING THEM.

The forms produced by destructive agencies, other things being equal, depend upon several controlling factors, which may act alone or in combination.†

CONTROLLING FACTORS.

I. *The character and alternation of the rocks.*

Erosion avoids the hard and seeks the softer rocks.

Harder sandstones resist, and make ridges.

Softer shales and clays yield, and make valleys. (See figs. 36, 37.)

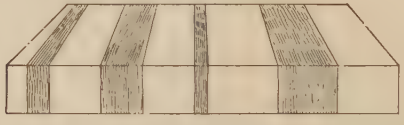

FIG. 36.—A smooth surface of alternate hard and soft rocks standing on end. The soft strata are shaded.

FIG. 37.—The same as Fig. 36 after being subjected to a period of denudation. The streams follow the softer strata.

Soluble limestones are carried off in solution, leaving caves and sink-holes.

* Tidal erosion in the Bay of Funday. By G. F. Matthew. Canadian Naturalist, New ser., 1881, IX, 368-373.

† Denudation with reference to....configuration, etc. By A. B. Wynne. Geol. Magazine, IV, 3-10. London, 1867.

In regions of alternate hard and soft beds, the topography is controlled more or less, according to circumstances, by the difference in the resisting powers of the rocks.

Influence of the varying character of sediments on the continuity of ridges and valleys.

Origin of "pulpit rocks," "chimney rocks," "table rocks," "bottle-rock." (See fig. 38)

FIG. 38.—A "pulpit rock" left by the removal of surrounding horizontal beds. (Hopkins.)

Exceptional character of the Tepee Buttes.*

II. *The geologic structure or position of the beds.*

Influence of the slope of the beds on the character of the topography.

Topography of horizontal beds.

Bench and bluff topography. (See figs. 40, 41, 42.)

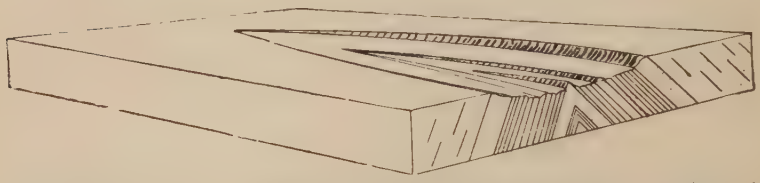

FIG 39.—Section across an anticline showing the influence of the rock fold upon the forms of the hills and valleys.

FIG. 40.—Bench-and-bluff topography. A region of horizontal beds. (Simonds.)

FIG. 41.—Profile of bench - and - bluff topography with alternate hard and soft strata.

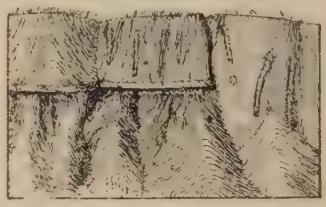

FIG. 42.—A bluff of homogeneous soft rocks with a single horizontal bed of hard rock. (Harris).

Grand Cañon. (See plate XIV.)

Mountains and hills of circumdenudation.†

Enchanted mesa. (See plates XV and XVII.)

*Tepee Buttes. By Gilbert and Gulliver. Bul, Geol. Soc. Amer., 1895, VI. 333-342.

†The Enchanted Mesa. By F. W. Hodge, Nat. Geogr. Mag., VIII, 273-284. Washington, 1897.

Horizontal sandstones at the summit of the Enchanted Mesa, near Acoma, New Mexico.
—From Land of Sunshine Magazine.

Topography of folded beds.*

Arkansas. †

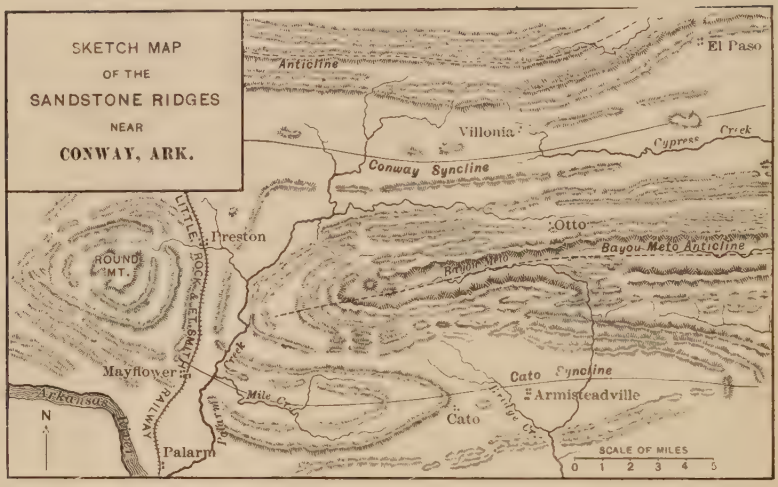

FIG. 43.—Sketch map showing the relation of folded and denuded beds of rock to topography. (Means)

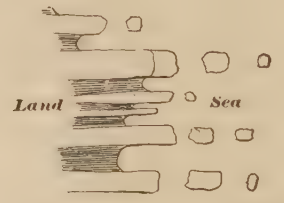

FIG. 44.—Plan of a coast of alternate hard and soft beds. The softer strata are shaded.

Sea-shore topography varying with the position of the beds in relation to the waves.

Influence of dip on the lateral movements of streams. (See p. 298.)

*Manual of coal and its topography. By J. P. Lesley. Philadelphia, 1856.
Some illustrations of the influence of geological structure on topography. By Benjamin Smith Lyman. Jour. Frank Inst. May, 1898, CXLV, 355-360.

† Physiographic geology of Western Arkansas. By Arthur Winslow. Bu. Geol. Soc. Amer. 1891, II, 225-242.

III. *Jointing or fracturing of the rocks.*

Influence of lines of weakness produced by joints and other breaks *

IV. *The slope of the land surface.*

The transporting power of a stream varies with the sixth power of the velocity.

Velocity is determined by the slope. It follows that the rate of cutting is determined by the slope.

Influence of settling basins on the work of streams.
Example : Great lakes and the St. Lawrence.

V. *Climatic conditions.*

Minor topographic features mostly carved by water.

Regions without water, subject to little or no change from this cause.

Blown sands of arid regions.

Origin of "hog-wallows."§

Effect of frost and moisture on rocks easily disintegrated.

Example: "Knobstone" of Indiana has gentle slopes facing southward.

Deserts.‖

VI. *Interruptions in development.*

The process of topographic development may be hastened, retarded, or entirely changed, by:

1. Landslides damming up streams and shifting divides.
2. Faults across streams producing falls, cataracts or lakes.

Examples: American valley, Calaveras valley, Sierra valley.

* Dutton's High plateaus of Utah, plate VII. 253, plate X., 280. Washington, 1880.
Daubrée's Géologie Experimentale, 300-374. Paris, 1879.

§Turner, 17th Ann. Rep. U. S. Geol. Surv. Part I, 681-4. Washington, 1896.
J. Walther. Die Denudation in der Wüste. 377. Leipzig, 1891.

‖Lapparent, Annales de Géographie, V. 1-14. Paris, 18

3. Lava flows damming streams, and diverting the old, or imposing a new drainage.
4. Glaciation filling old depressions, scooping out basins, and compelling a new drainage.*
   Moraines damming water in valleys.
   Donner lake.
   Seattle lake.
   Kettle moraine region of Wisconsin and Minnesota.
5. Depression carrying the region beneath the sea.
   The origin of fjords and harbors.†

VII. *The primitive drainage.*

Sinking of land beneath the sea, and the deposition of new beds upon the old topography.

When such areas are re-elevated, the drainage of the new surface is determined by general slope and local accidents.

Cutting their channels downward, the streams reach and uncover the buried topography.

The channels are already determined, however.

Such drainage is said to be ***superimposed.***

In the main, it is often quite independent of the geologic structure in which it ultimately flows.

There is a tendency, however, for such drainage to come more and more under the influence of the geology.

VIII. *The length of time the region is exposed to erosion.*

Erosion attacks all land surfaces.

It follows that the longer these surfaces are exposed to erosion, the more they are eroded.

Topography of any area, therefore, changes constantly.

* Glacial origin of certain lakes of Switzerland. A. C. Ramsay, Quar. Jour. Geol. Soc. 1862. XVIII, 185–204.

Physical geology and geography of Great Britain. By Sir A. C. Ramsay. 264–275. 6th ed. London, 1894.

Glacial erosion, By W. M. Davis. Proc. Bost. Soc. Nat. Hist. XXII, 19–58. Boston. 1884.

† The geological history of harbors. By N. S. Shaler. Thirteenth Ann. Rep. U. S. Geol. Surv. Part II, 93–209. Washington, 1893.

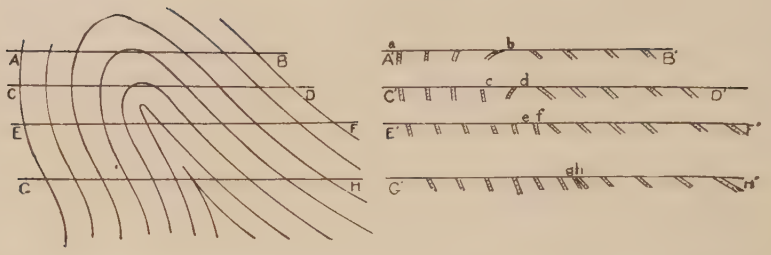

FIG. 45.—Diagrams illustrating the structures shown by eroding an overturn to different depths. (Ashley.)

In general, there is a tendency to smooth down irregularities and to reduce all to a common low level.

IX. *The nature and working methods of the eroding agency.*

Erosion is done mostly by water and ice in motion.

Erosion done by water tends to cut deep, narrow gullies and gorges on the land, and to undercut sea and lake shores, and to spread out silts over flood-plains and sea-bottoms.

Erosion by ice tends to round off small surface irregularities, while its load is left in the form of moraines.

VALLEYS.

General forms.

I. V-shaped and inverted A-shaped.
II. U-shaped.
III. With gently sloping sides.

VALLEY-FORMING AGENCIES.

1. *Erosion.*

Most of our narrow valleys, cañons, gulches, gorges, ravines, etc., have been made by this agency.

These are mostly steep-sided.

Examples: Yosemite, Tuolumne, Colorado.

(See "Streams," page 296.)

2. *Folding.*

Example: Lackawanna-Wyoming.

3. *Faulting.**

Examples: Northern California and Oregon Coast ranges and their parallel valleys. (See plate XVIII).

Valleys not always washed out along fault lines.

* Valleys and their relations to fissures, fractures, and faults. By G. H. Kinahan. London, 1875.

PLATE XVIII.

Photograph of Drake's relief-map of the State of California, showing the northwest-southeast valleys, partly due to faulting. (Drake.)

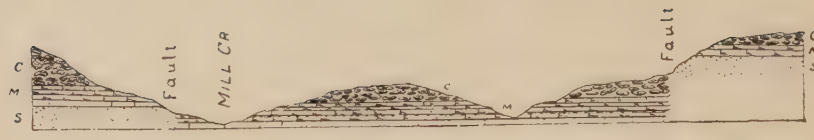

FIG. 46. Vertical section across two faults that have affected the topography but little.

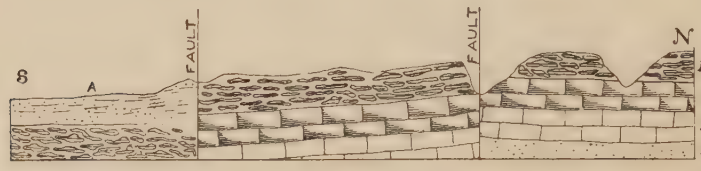

FIG. 47. Vertical section across two faults and two valleys in the Ozark mountains. Only one of the faults has yielded a valley.

4. *Building up the sides.*

Such valleys lie between volcanic mountains.
Examples: Central France, Hawaii.

AGENCIES MODIFYING VALLEYS.

1. Ice erosion and moraines.
   Examples: Yosemite, Lackawanna.
2. Filling in when dammed up.
   Examples: Calaveras, American, Sierra.

LAKES.*

Lake basins originate in some of the following ways:

I. Scooping out of basins by glaciers.
II. Damming back the waters by:
   1. Landslides.†

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* Les lacs du Jura. Par Ant. Magnin. Ann. de Geogr., 1894. III, 213-226.
Lakes of North America. By I. C. Russell. Boston, 1895.
The English lakes. By H. R. Mill. Geogr. Jour., July-Aug., 189.5
Present and extinct lakes of Nevada. By I. C. Russell. Physiography of the United States, 101-136. New York, 1897.
Jour. Geol., 1896, IV, 647-8.
An account of the researches relating to the Great Lakes. By J. W. Spencer. Amer. Geologist, Feb., 1898, XXI, 110-123.
The formation and deformation of Minnesota lakes. By C. W. Hall. Science, 1893, XXI, 314. Par André Delebecque. Paris, 1898.
Les lacs français.

† Topographic features due to landslides. By I. C. Russell. Pop. Sci. Monthly. Aug., 1898, LIII, 480-489
The landslip at Gohnah, India. Nature, July 5, 1894. L, 231-234; 428; 501.

2. Existing glaciers.
3. Moraines left across valleys.
4. Igneous outflows across drainage.
5. Faults rising across the drainage.
6. Shore accumulations or *cordon littoral*.*
7. Sand dunes.

III. Cutting off of basins by silting up.
Examples: Salton lake,† Interlaken, Switzerland, Vale of Kashmir.‡

IV. Orographic movements.

V. Depressions caused by solution of rocks.
Sinkholes and ponds of limestone regions of Tennessee, Kentucky, etc.

VI. Extinct craters.
Crater Lake, Oregon.§
West side of Mt. Hood.

STREAMS AND THEIR CHANGES.¶

The age of streams.

Newer than the beds over which they flow.
Examples:
Importance of initial conditions.

Consequent streams.

Streams whose positions are determined by the slope of a new surface.

*Les lacs français. Par André Delebecque. 280–284, plates XVII, XVIII, XIX. Paris, 1898.

†Salton Lake. By E. B. Preston. 11th Ann. Rep. State Mineralogist of Calif., 387-393. Sacramento, 1897.

‡Climbing and exploration in the Karakorum-Himalayas. By W. M. Conway. 37. New York, 1894.

§Crater lake, Oregon. By J. S. Diller. Nat. Geographic Mag., VIII, 33-48. Washington, 1897.
Mazama, I, 139-293. Crater Lake Number. Portland, Or., 1897.

¶On the physical features of the valley of the Colorado. Part II, 147-214, of the Exploration of the Colorado River of the West. By J. W. Powell. Washington, 1875.
The rivers of northern New Jersey. By W. M. Davis. Nat. Geogr. Mag., II, 81–110. Washington, 1890.
The rivers and valleys of Pennsylvania. By W. M. Davis. National Geographic Magazine, Washington, 1889, I, 183-253.
Leçons de geographie physique. Par A. de Lapparent, 109-130. Paris, 1896.
Drainage modifications and their interpretation. By M. R. Campbell. Jour. Geol., 1896, IV, 567-581; 657-678.
How rivers work. The Physical Geography of New Jersey. By R. D. Salisbury, 70-82. Trenton, 1898.
Rivers and river valleys. Aspects of the earth. By N. S. Shaler, 143-196. New York, 1889.

Subsequent development depends chiefly upon the geology.
Regions of horizontal rocks.
Regions of folded rocks.
Shifting of channels due to dip. (Figs. 48 and 49).

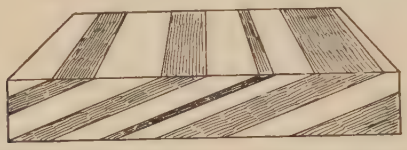

FIG. 48.—A smooth surface of hard and soft rocks dipping toward the left. The soft layers are shaded.

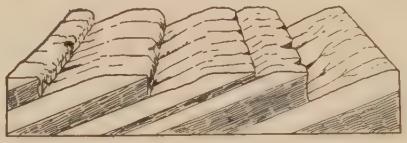

FIG. 49.—The same as Fig. 47 after being subjected to a period of denudation. The stream follow down the slopes of the soft strata.

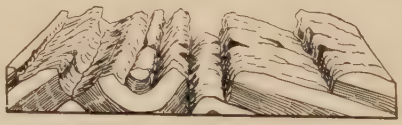

FIG. 50.—A region of folded beds showing the streams following the soft and avoiding the hard ones.

Superimposed streams.

Superimposed streams have cut down from initial conditions that were developed, regardless of the present structure. Example: South Arkansas.

Antecedent streams.

Antecedent streams are those that hold and cut their way through obstacles rising across their courses.

New cycles of erosion are brought about by interruptions of a msyste of drainage.

The winding of upland streams.
Superimposed; developed drainage.*
The winding of lowland streams.

*A. Winslow. Science, 1893. XXIII, 312.
C. F. Marbut. Amer. Geol. Feb. 1898. XXI, 86-90.

TERRACES.*

Terraces may be produced by:

1. The cutting of waves along a shore.**
2. The cutting of a meandering stream.
   Why the highest terraces are the oldest.
   Why stream terraces are often in pairs.
3. The differential resistance (to erosion) of horizontal beds.

EFFECTS OF TOPOGRAPHY UPON CIVILIZATION.***

Relations of topography to.

- I. Political boundaries.
- II. Harbors and marine industries.†
- III. Location of cities and manufactures.‡
- IV. Art.
  Scenery.§
- V. Agriculture.
- VI. Literature.‖

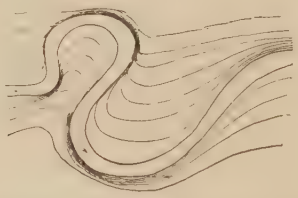

FIG. 51.—A meandering upland stream cutting its way down through homogeneous rocks, and getting more crooked.

*Geographical development of alluvial terraces. By R. E. Dodge. Proc. Bost. Soc. Nat. Hist. 1895. XXVI, 257–273.

Ohio terraces, Amer. Geol. 1896. XVIII, 227.

H. H. Smith. Brazil, the Amazon, and the coast. 631–2. New York, 1897.

**Raised shore-lines on Cape Maysi, Cuba. By O. H. Hershey. Science, Aug. 12, 1898. VIII, 179-180. Hill, Nat. Geogr. Mag. IX, 242. Sketch by A. Agassiz, Nat. Geogr. Mag. IX, 200, 208.

The topographic features of lake shores. By G. K. Gilbert. 5th Ann. Rep. U. S. Geol. Surv. 69–123. Washington, 1885.

***Nature and man in America. By N. S. Shaler. New York, 1891.

†The geological history of harbors. By N. S. Shaler. 13th Ann. Rep. U. S. Geol. Surv. Part II, 93–209. Washington, 1893.

‡McGee, Am. Jour. Sci. 1890, CXL, 16.

§The scenery of Switzerland and the causes to which it is due. By Sir John Lubbock. New York, 1896.

The scenery of Scotland viewed in connection with its physical geology. By A. Geikie. Second ed., London and New York, 1887.

Landscape geology: a plea for the study of geology by landscape painters. By Hugh Miller. Edinburgh and London, 1891.

‖Types of scenery and their influence on literature. By Sir Archibald Geikie. London, 1898.